The coming of age of China's offshore wind energy:

Opportunities for the maritime sector

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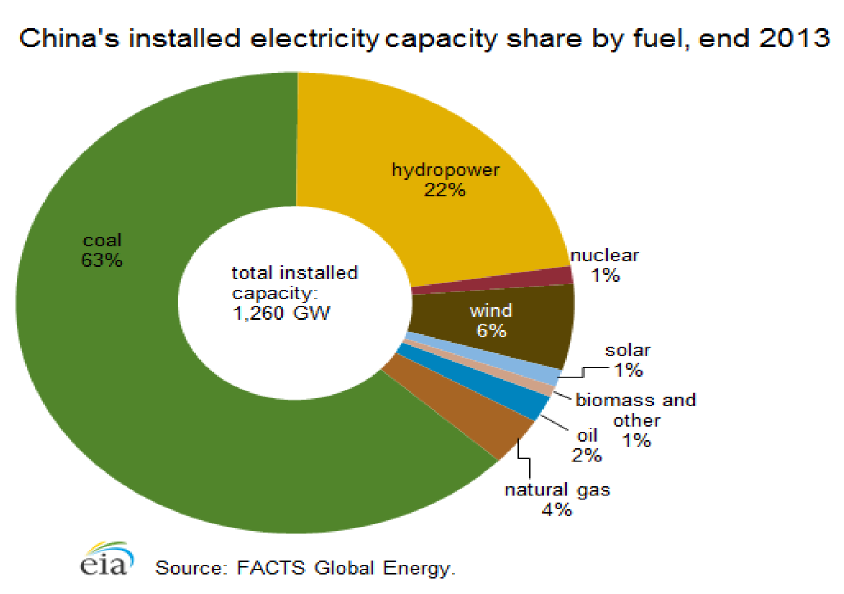
GEOGRAPHY ENVIRONMENT & DEVELOPMENT STUDIES

China and the need for clean energy

- China’s energy demand has grown by 150% over the past decade
- now the world’s largest energy user. The majority of growth has come from coal energy
- estimated costs of air and water pollution in China range from 3–6% of China’s annual economic output
- China is actively scaling up deployment of renewable energy, now leads the world in installed capacity of renewable energy and in wind generation capacity
- growth in wind generation surpassed growth in coal-fired electricity for the first time in 2012.



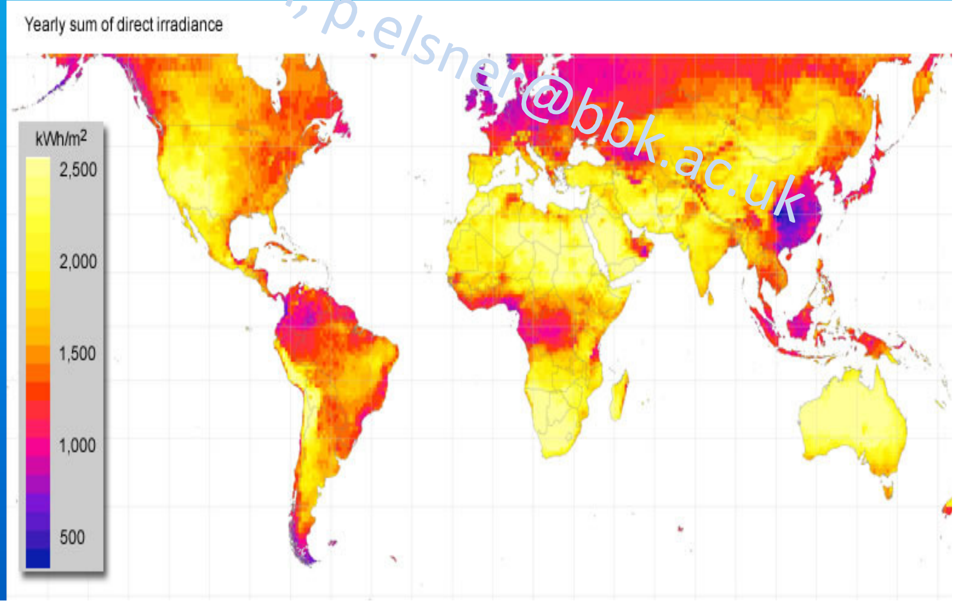


Fig.1.3.3. China's onshore wind generation vs. provincial electricity demand

1. 2003 Estimate
Source: CWEA (2008), China State Power Grid Co., LBS Team Analysis

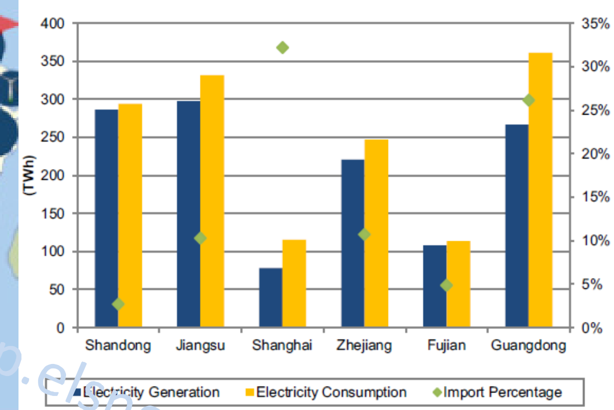


Fig. 3. Electricity generation and consumption in coastal provinces in 2009 [38,39].

From: Wyatt et al., 2014

- Challenge to link-up supply and demand centers
- End of 2012, about 20% of wind generation capacity not connected to the grid
- high curtailment of grid-connected wind resources (17%) as electricity could not be absorbed by exiting grid

China Offshore Wind Potential

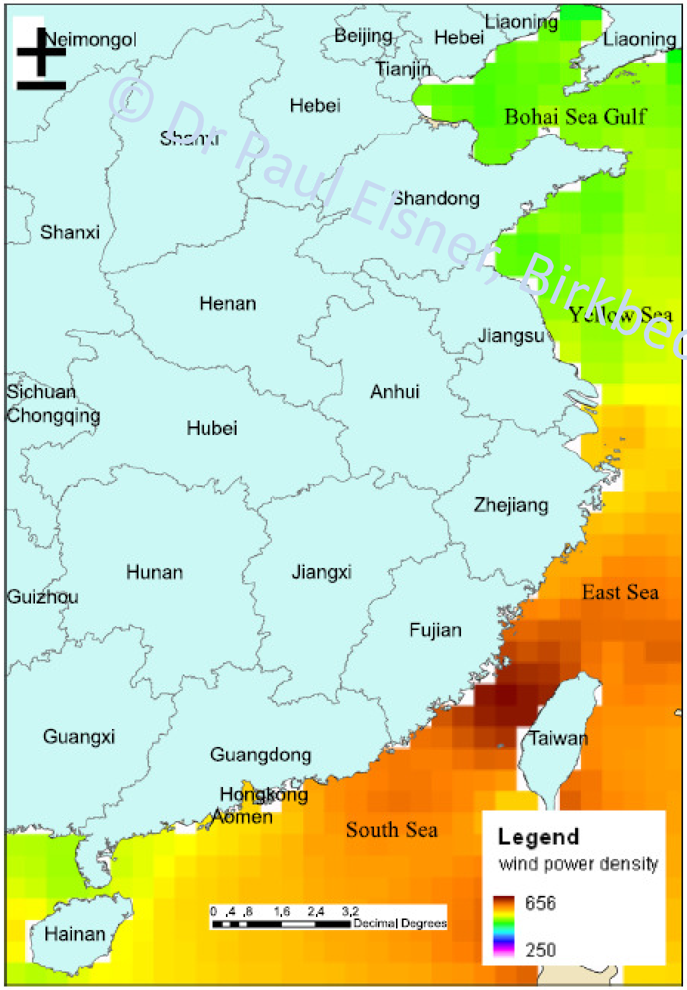


Fig. 5. Nine-year average annual wind power density map of coastal regions of China (W/m^2).

From: Jiang et al., 2013

- The offshore wind potential off China's east coast has been estimated at 200 GW within water depth <25m, with an additional 300 GW available in water depths between 25m and 50m
- most abundant wind resource located in the Taiwan Strait. Offshore areas near Fujian, southern Zhejiang, and Guangdong are therefore prime locations to maximise this wind resource
- average wind speeds in Fujian are ~10m/s
- other provinces with typical average wind speeds of 6-8m/s, which still represents very good wind resource
- wind resource therefore sufficient for significant offshore development, particularly in northern Zhejiang and Jiangsu. Jiangsu alone has an estimated potential near-offshore capacity of 14 GW and at depths of 5 to 25m

Taifun probability and investment risks

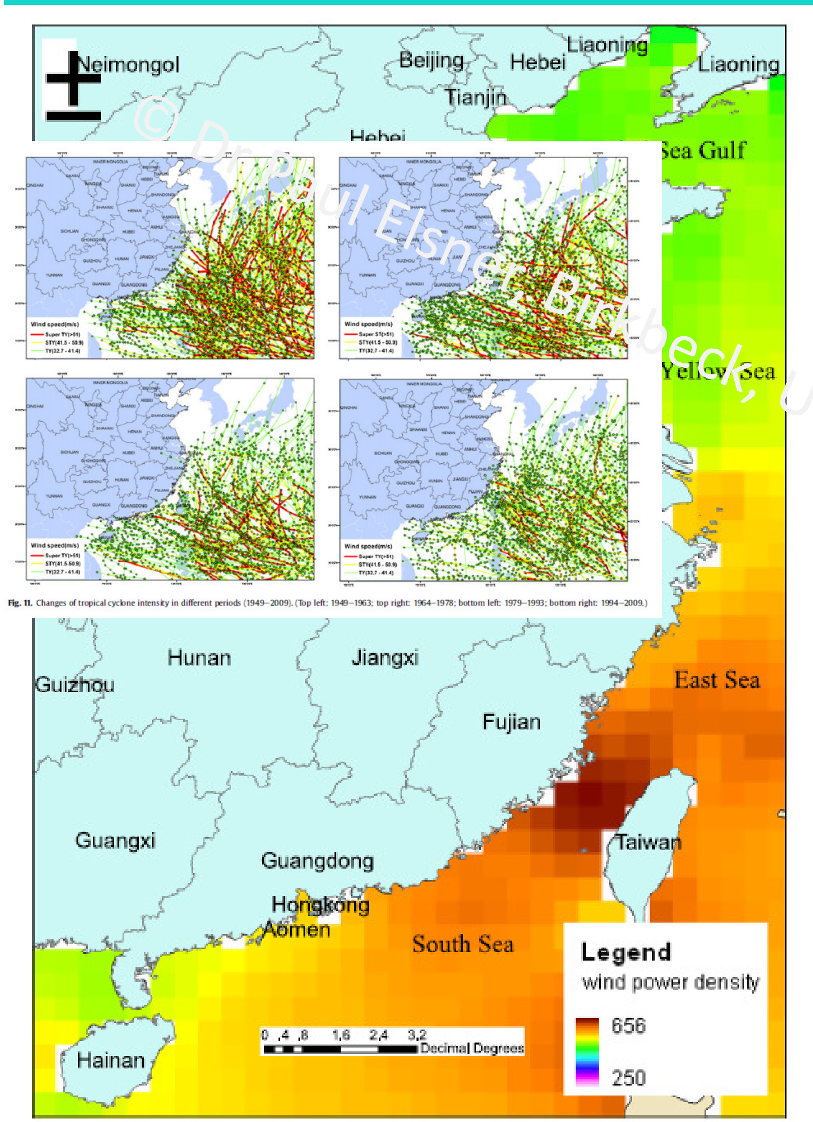


Fig. 5. Nine-year average annual wind power density map of coastal regions of China (W/m^2).

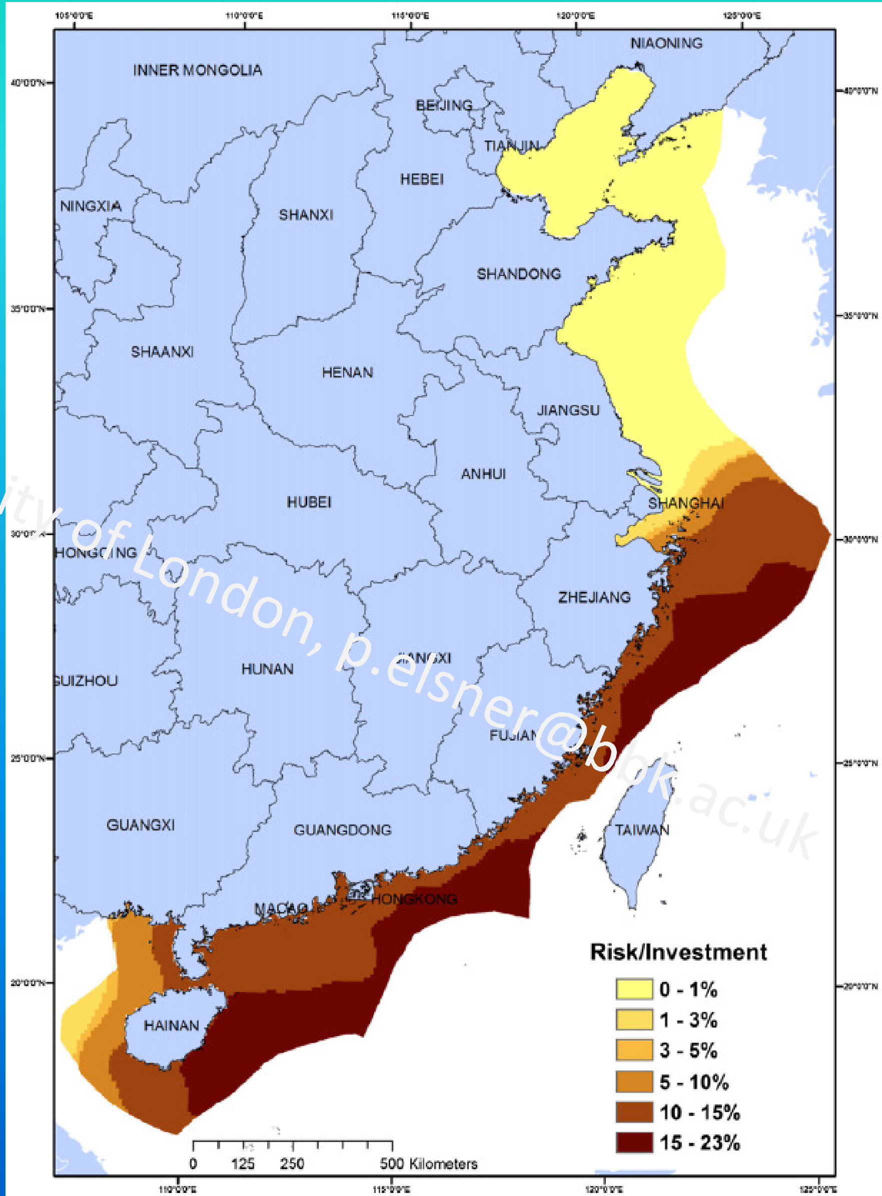


Fig. 3. The percentage of economic risk in investment cost.

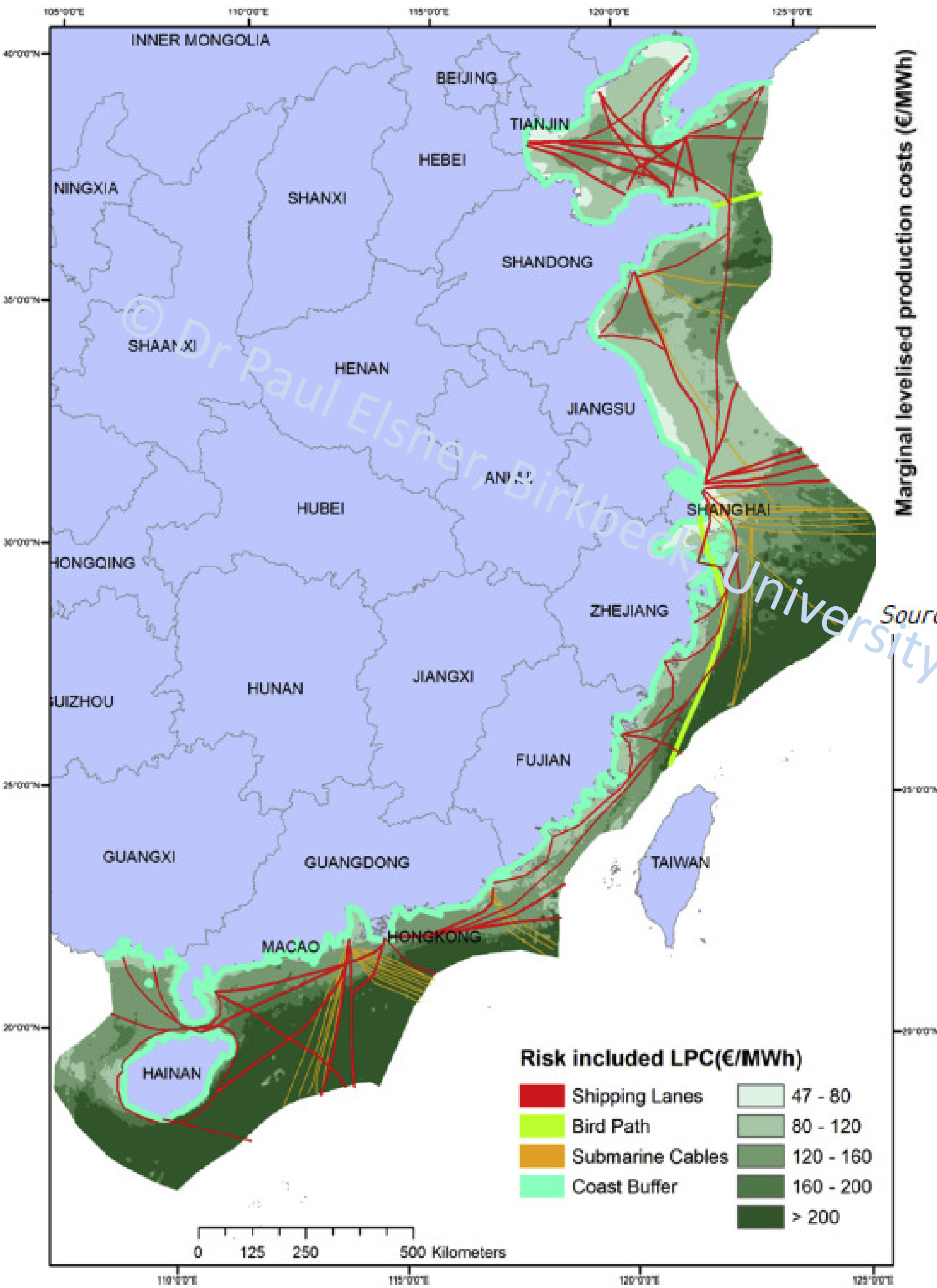
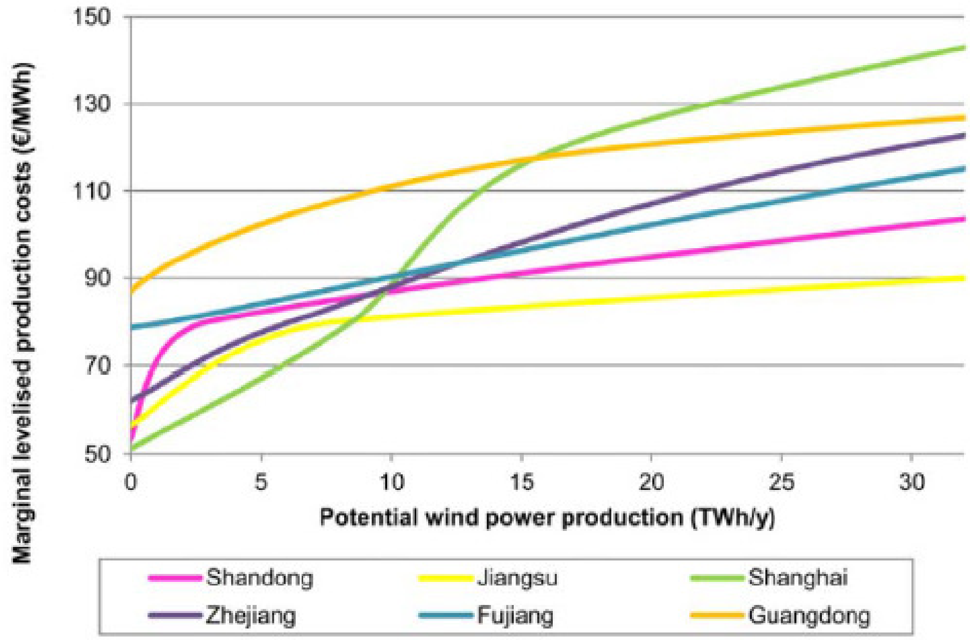


Fig. 6. Spatial distribution of LPC under tropical cyclone risk and spatial constraints.



Source: Hong & Moller (2012).

- lowest cost sites for offshore wind development are along the coasts of Jiangsu, Shanghai, Hebei, and Tanjin
- economic risk of tropical cyclones are fairly high in both Fujian and Guangdong.
- in the short term Shanghai is the most economically competitive location.
- In the long term, Jiangsu emerges as the most cost competitive province for the large-scale development of offshore wind farms, due lack of spatial constraints from shipping routes and marine conservation zones, and lower risk from tropical cyclones

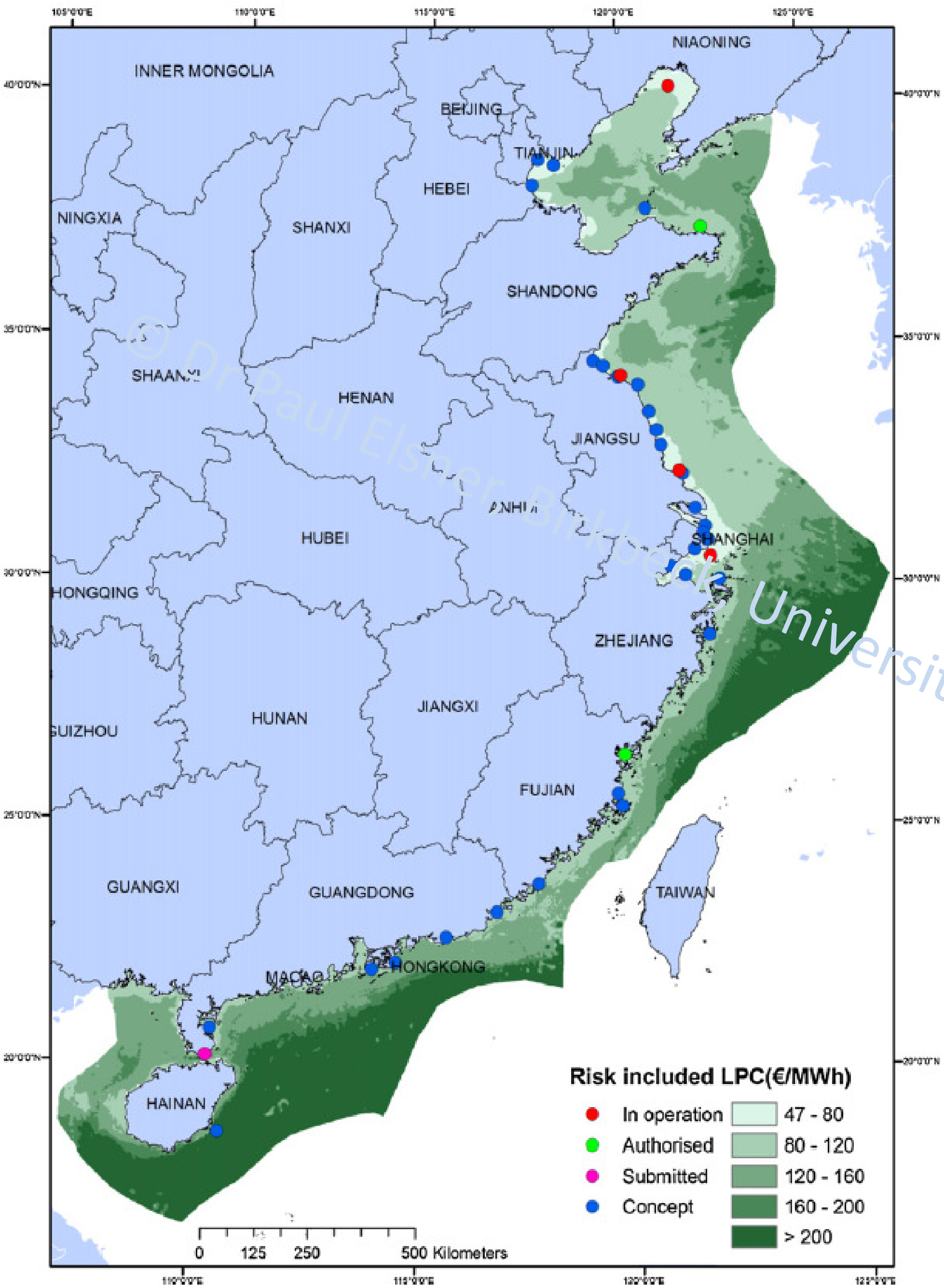


Fig. 4. Spatial distribution of tropical cyclone risk included LPC for offshore wind farms.

China (W/m^2).

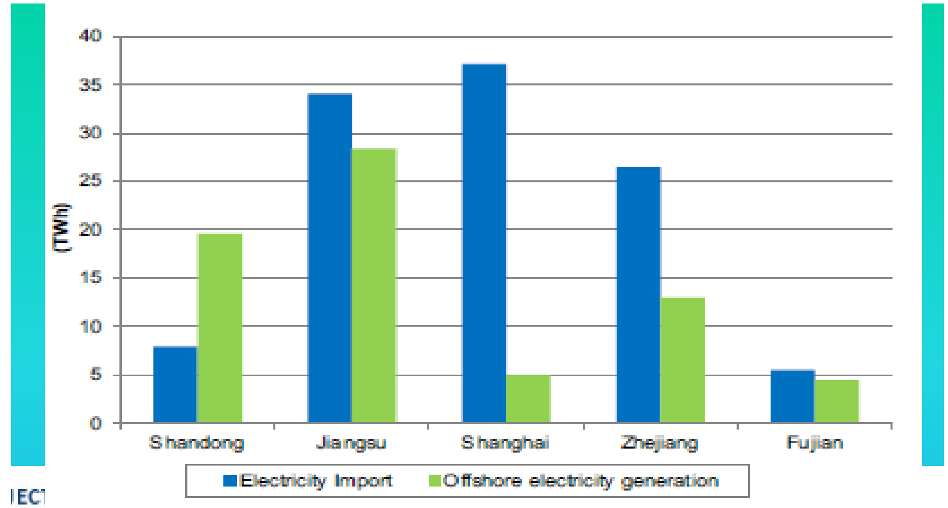
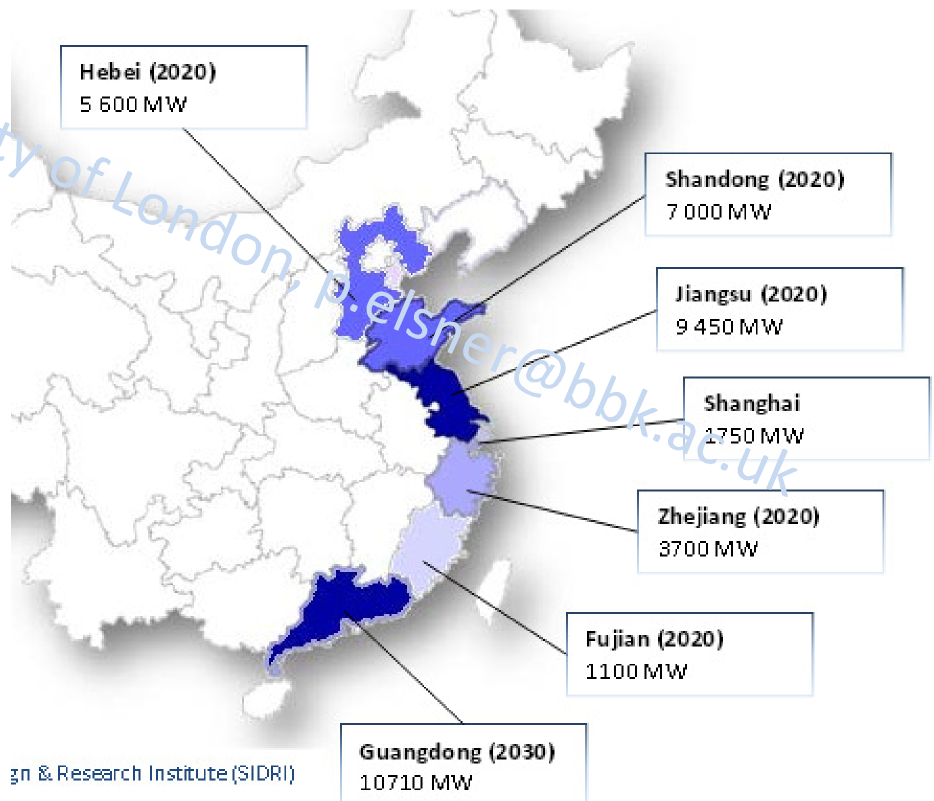


Fig. 4. Imported electricity in 2009 compared to offshore wind generation in 2020.

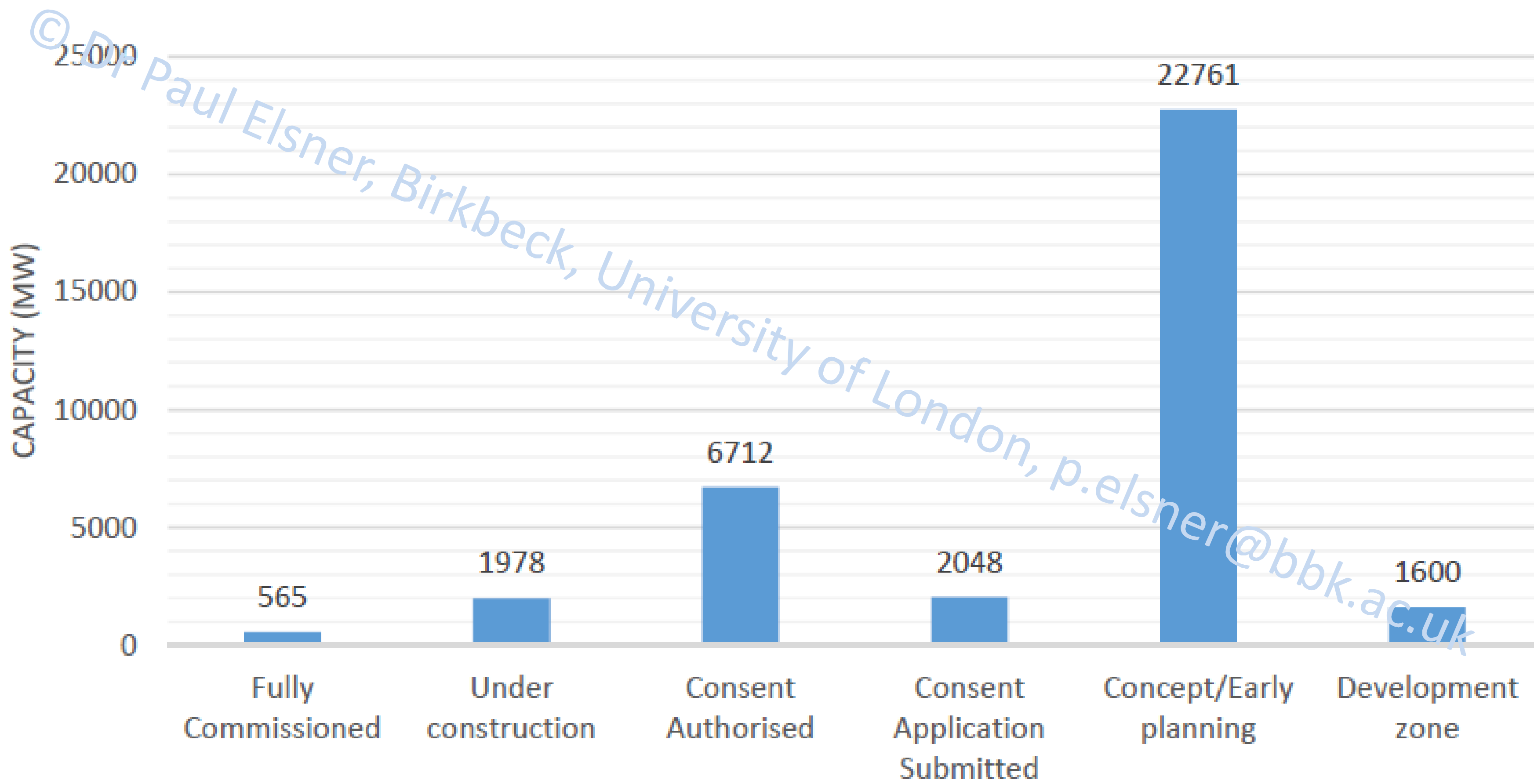


:for 2030.

From: Hong and Moller (2012), Innovation Norway (2013)

Status of China's offshore wind plans

Fig.1.4.3. Status of China's offshore wind projects (installed and pipeline)



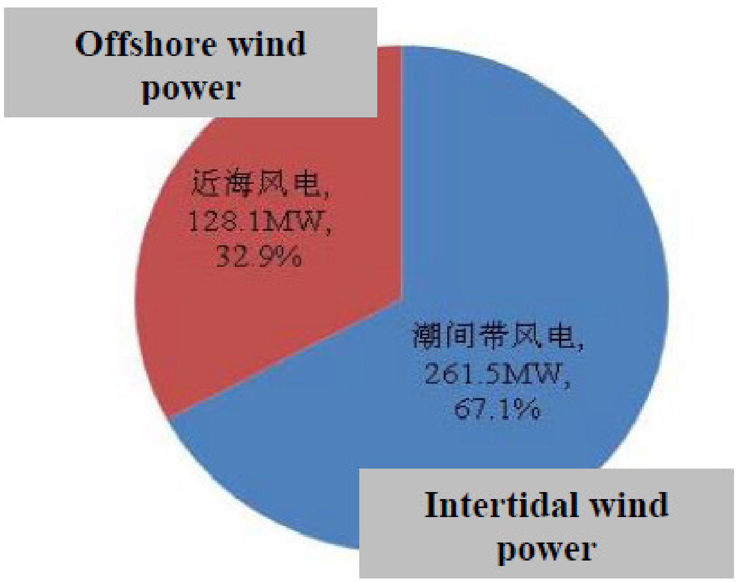
Source: www.4coffshore.com; Carbon Trust analysis

From: Wyatt et al., 2014

Intertidal, onshore with 'wet feet'

- large majority of early projects are intertidal (Donghai Bridge, 102 MW, 34 3MW Sinovel turbines)
- new regulations by National Energy Administration (NEA) and the State Oceanic Administration (SOA) outline that future offshore wind farms should be located no less than 10km from shore and in water depth no less than 10m if the width of the tidal flat is <10km.

Fig.1.5.1. Installed capacity in intertidal and offshore areas in 2012

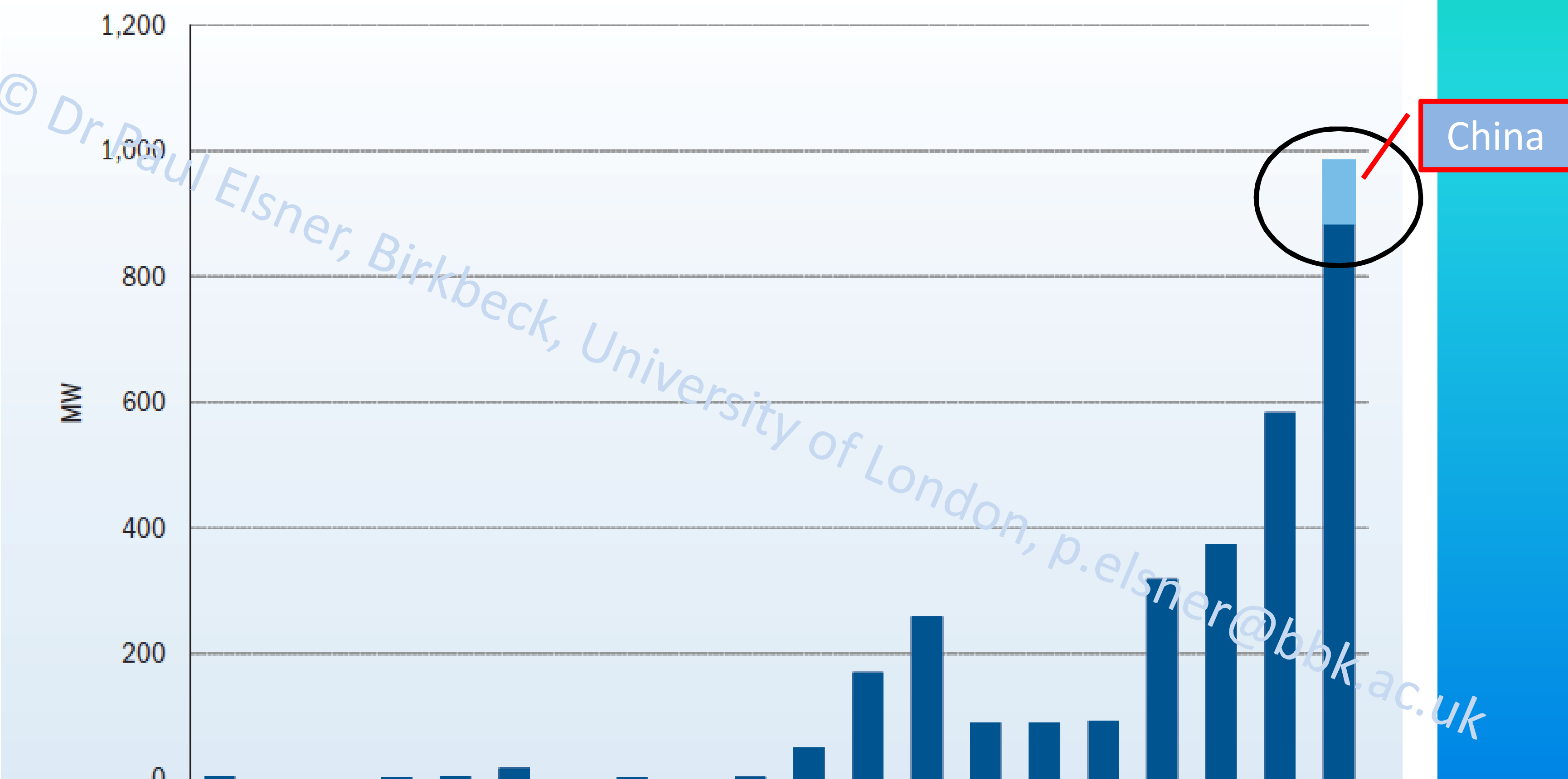


Source: CWEA (2013).

From: Wyatt et al., 2014

The Global Offshore Wind Market

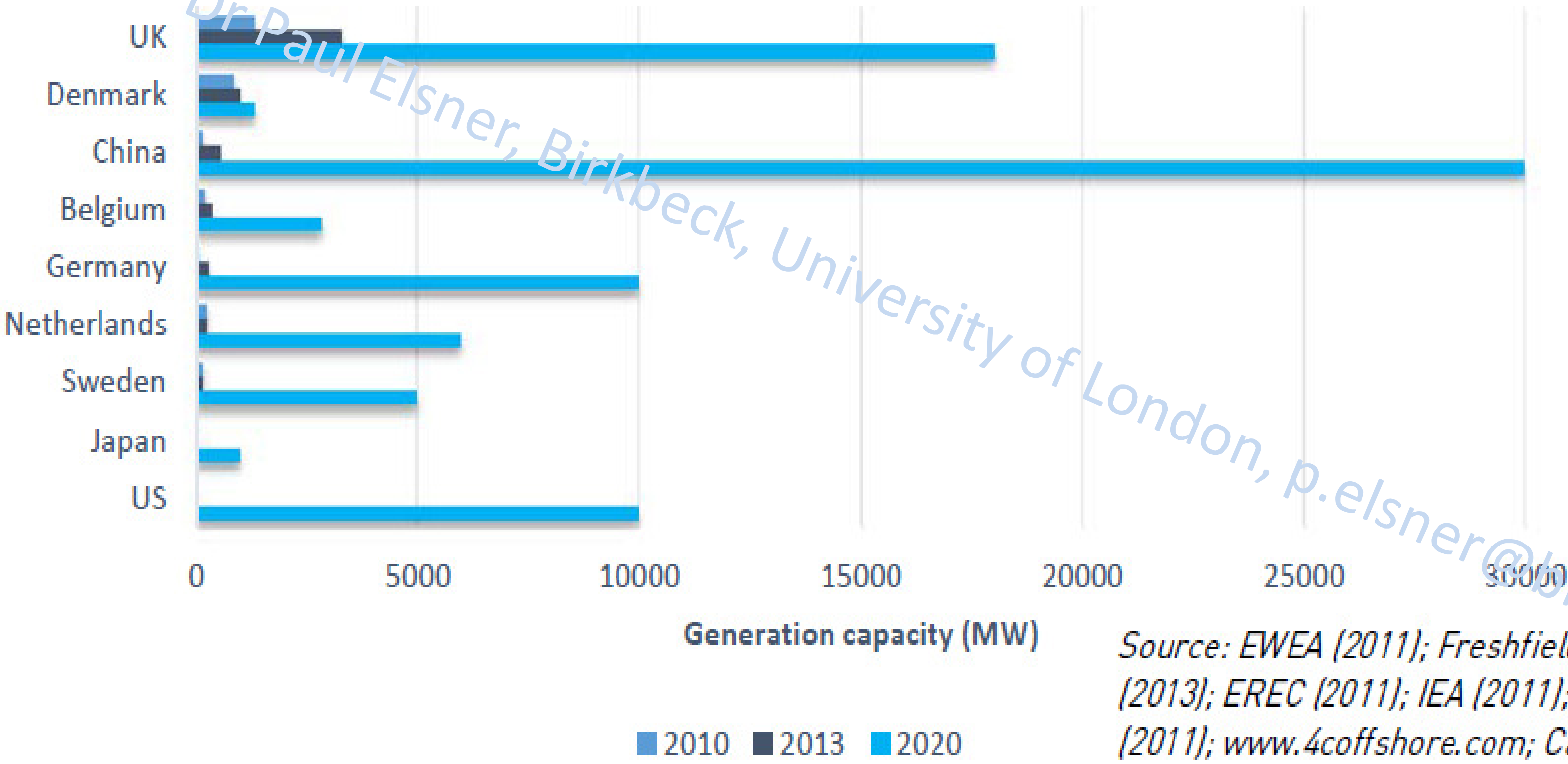
FIGURE 1.2 ANNUAL OFFSHORE WIND CAPACITY – EU AND NON EU (1991-2010)



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Annual non-EU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102
Annual EU	5	0	0	2	5	17	0	3	0	4	51	170	259	90	90	93	318	374	584	883

Source: EWEA

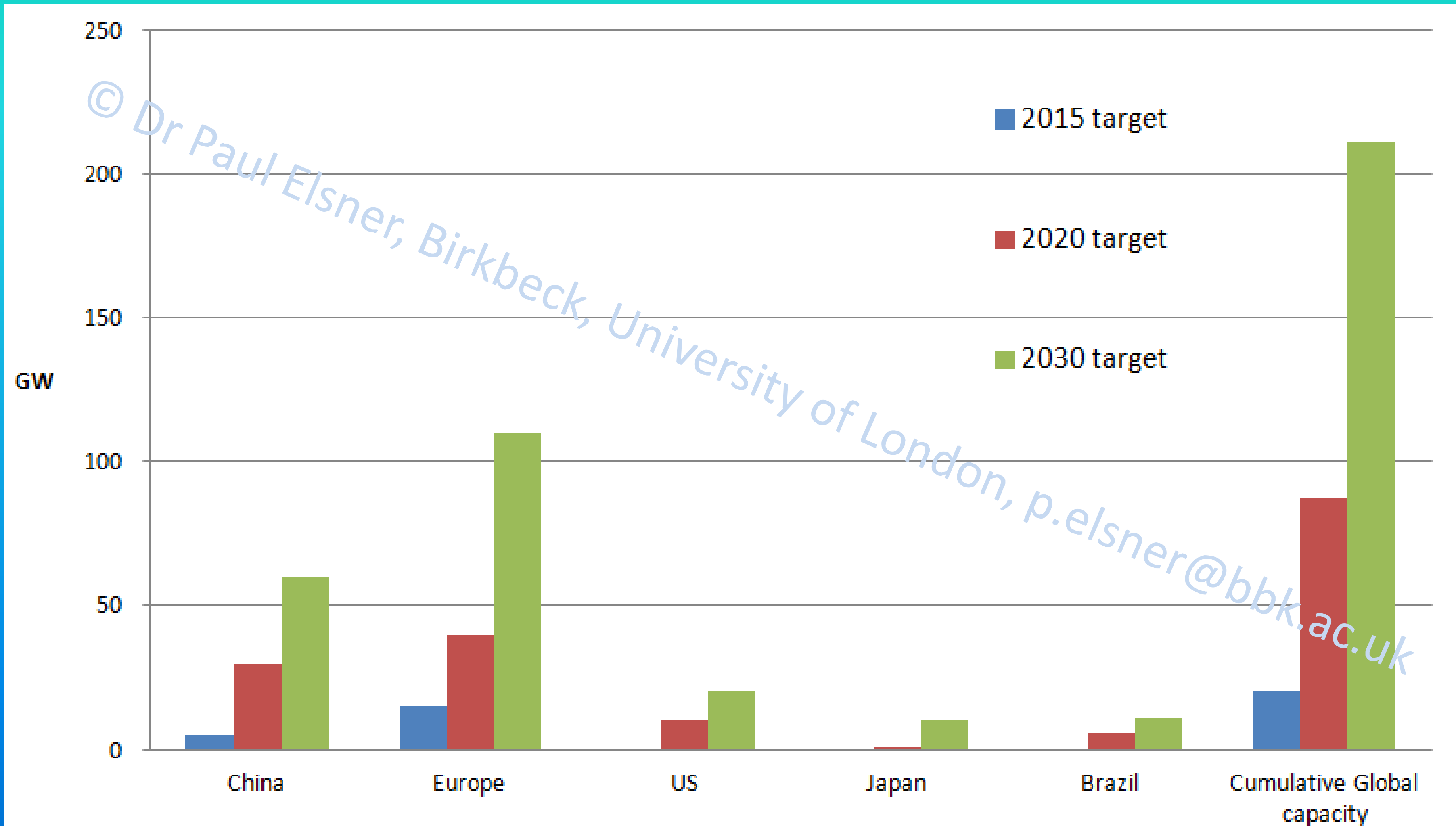
National offshore wind capacity targets to 2020



Source: EWEA (2011); Freshfields Bruckhaus Deringer (2013); EREC (2011); IEA (2011); U.S. Dept of Energy (2011); www.4coffshore.com; Carbon Trust analysis.

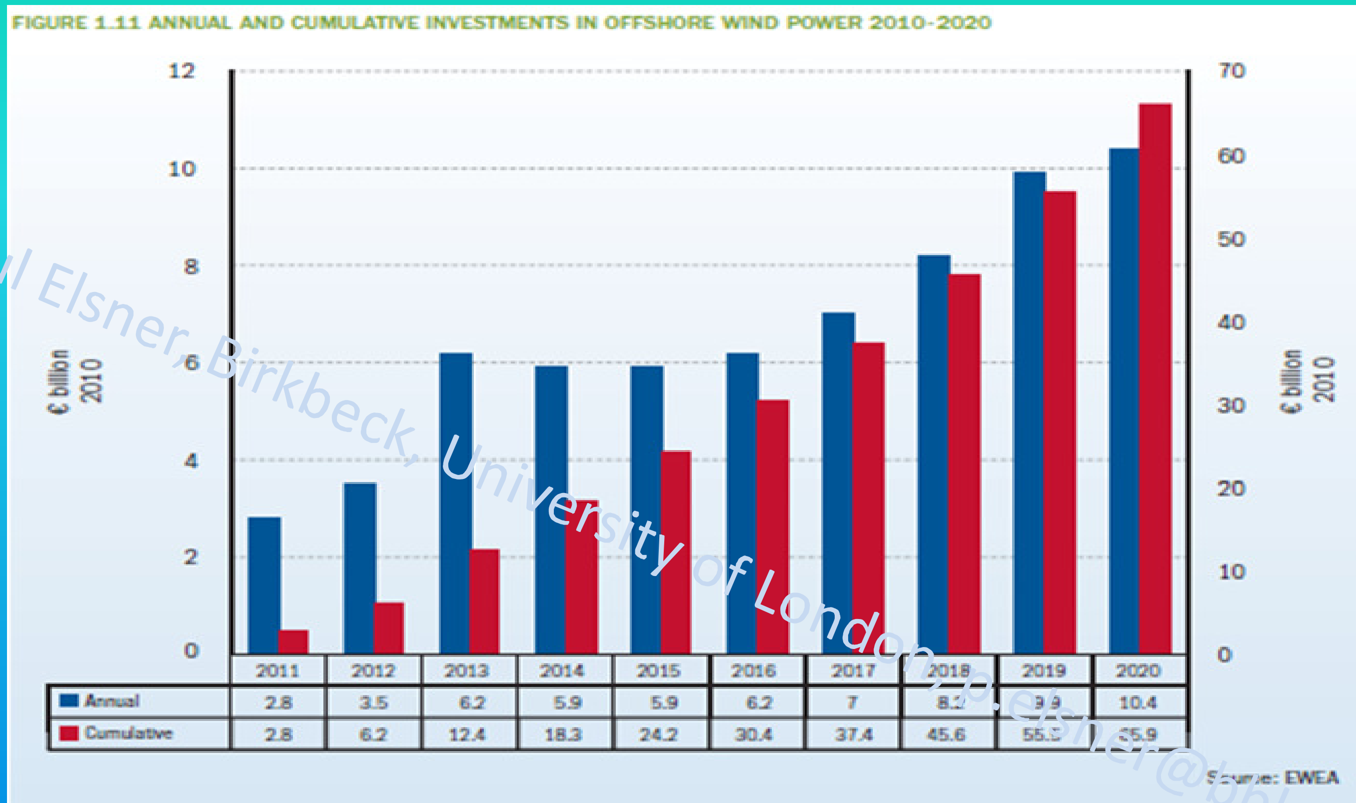
From: Wyatt et al., 2014

Long-term trends for offshore wind targets: The rise of a new market for the maritime sector



Based on data from Zhao and Ren (2015), EWEA, Rodriguez et al. (2015)

Offshore Wind Investments



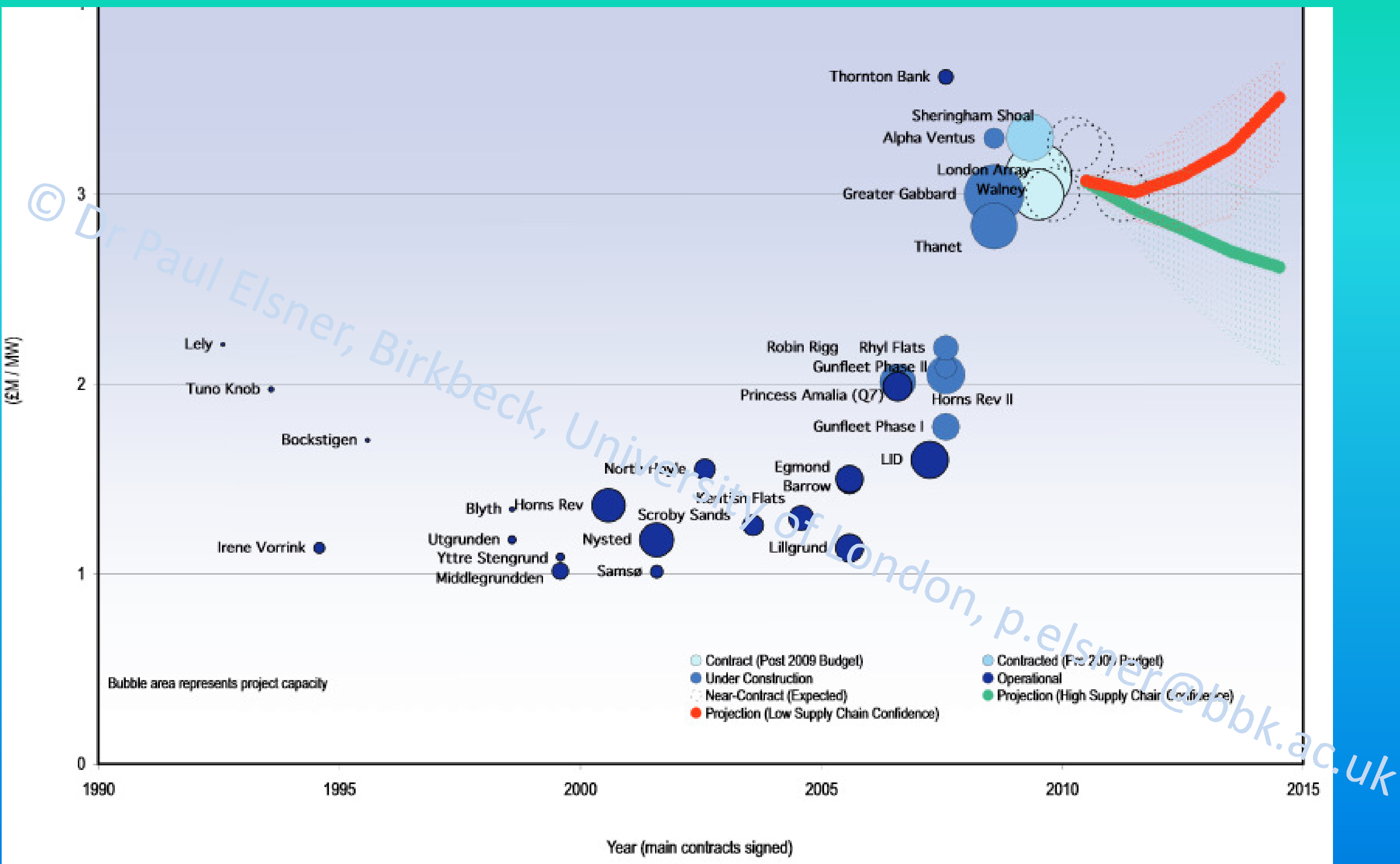
- EU: 68 billion € investment to install ~40 GW capacity (1.7 million €/MW)
- Chinese target of 30 GW: ~ **<u>50/60 billion €/US$</u>**

OWP opportunities for the maritime industry: More than 50% of project costs for infrastructure and installation

TABLE 4.5: CAPITAL COST STRUCTURE OF OFFSHORE WIND POWER SYSTEMS, 2010

	Share of total cost (%)	Cost (USD/kW)	Sub- Components	Cost share of sub-components (%)
Wind turbine	44	1 970	Nacelle Blades Gearbox Generator Controller Rotor hub Transformer Tower Other	2 20 15 4 10 5 4 25 15
Foundations	16	712	-	-
Electrical infrastructure	17	762	Small array cable Large array cable Substation Export cable	4 11 50 36
Installation	13	580	Turbine installation Foundation installation Electrical installation	20 50 30
Planning and development	10	447	-	-
Total	100%	4 471		

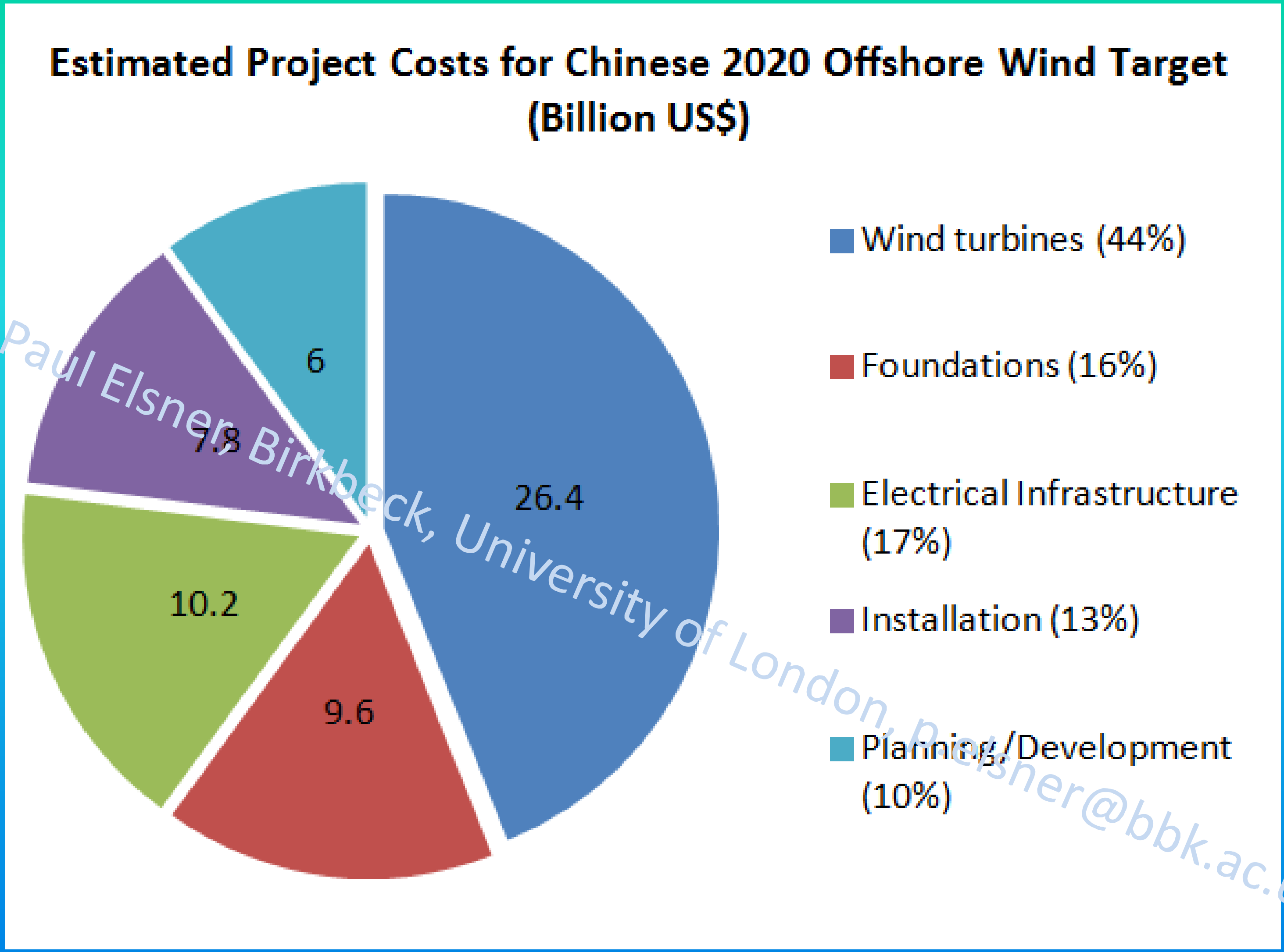
From: IRENA, 2012



Historical, current and projected future capital costs for offshore wind projects

Dr Paul Elsner (p.elsner@bbk.ac.uk)

From: BWEA, 2009



- 60 billion US$ total project costs (assuming 2 million US$/MW)
- 46% of project costs are core maritime activities
- equivalent to approximately 27 billion US$ maritime expenditure for Chinese offshore wind for 2020 target

European OWP investments in next decade

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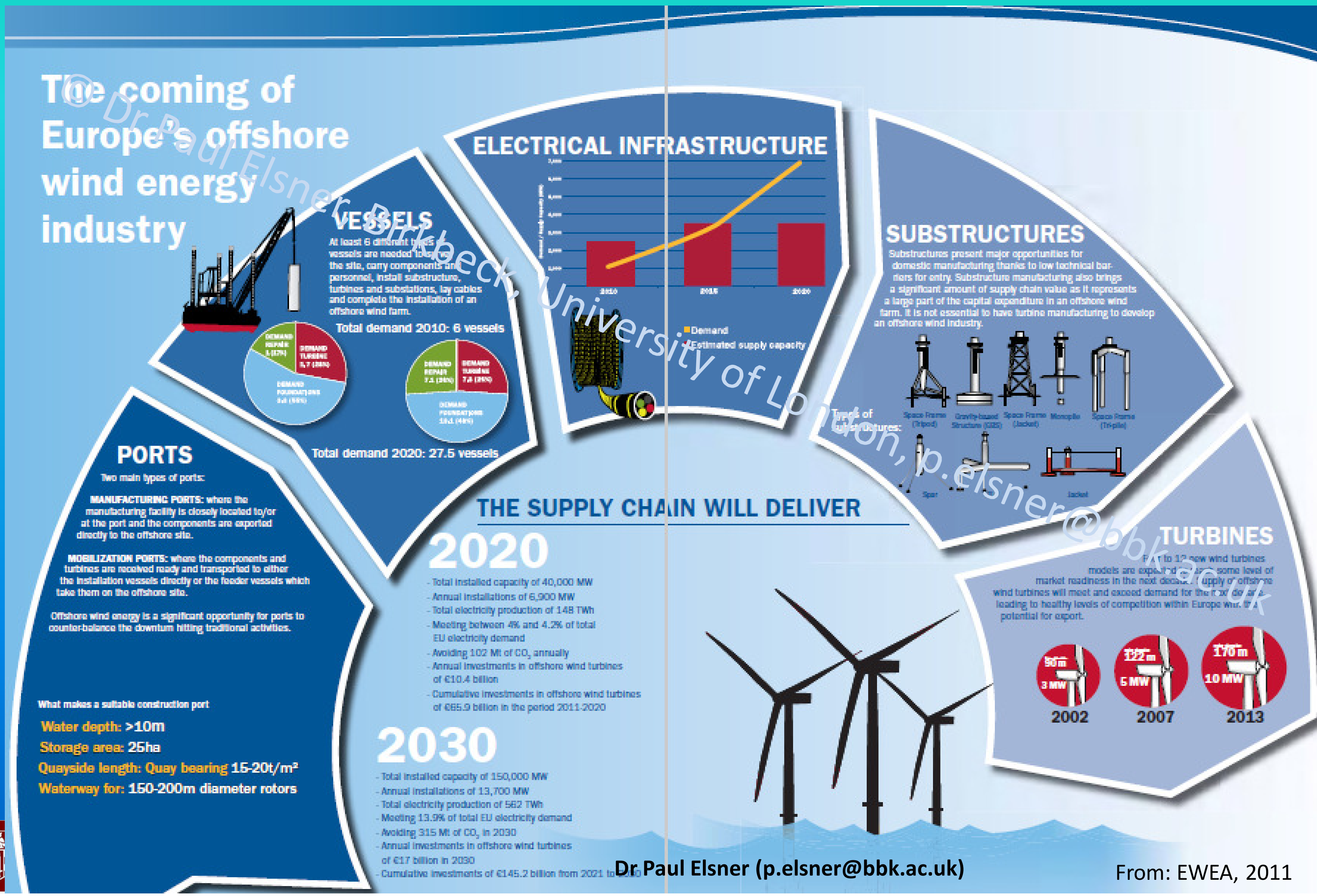
Developing the offshore wind supply chain



Dr Paul Elsner (p.elsner@bbk.ac.uk)

From: EWEA, 2011

Installation vessels

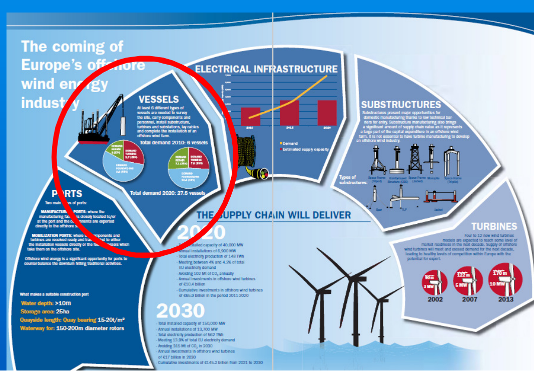
- installation major cost factor, daily rate ~200 000 US$ /day (Vattenfall)
- supply of bespoke offshore wind installation vessels is currently only just keeping pace with demand in Europe
- European demand expected to grow
- suppliers are unlikely to free-up their vessels for use in China

Jack-up vessel
Excalibur

Leg-stabilised crane vessel
A2Sea Sea Power at Lillgrund

DP2 Heavy lift cargo vessel
Jumbo Javelin

Semi-submersible heavy lift vessel
Thialf at Alpha Ventus



Need for specialised installation solutions

- China's soft seabed conditions are not well-suited to jack-up vessels which dominate the European market
- need for more challenging floating installation vessels.
- joint venture Shanghai Zhenhua Heavy Industries (ZPMC)/ Longyuan Power Group developed two offshore wind installation vessels tailored to China's coastal and hydrological conditions (Donghai Bridge project)
- lack of skills in hammering techniques and offshore assembly to scale up installation to required capacity

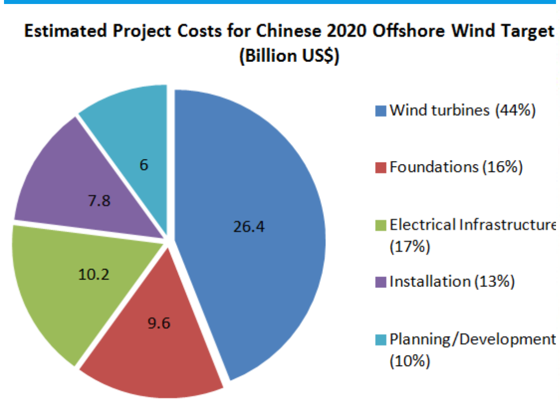


Fig.6.3.3. ZPMC's smaller, offshore wind farm installation platform.

Source: www.zpmc.com

Fig.6.3.4. ZPMC's larger, offshore win farm installation vessel.

Source: www.zpmc.com

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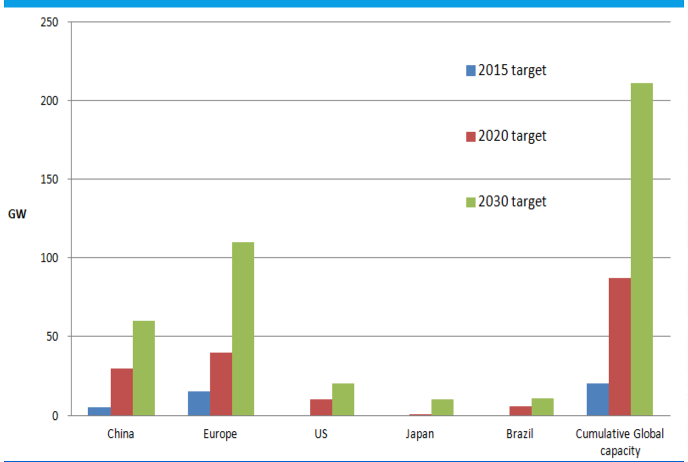
China’s demand for installation vessels

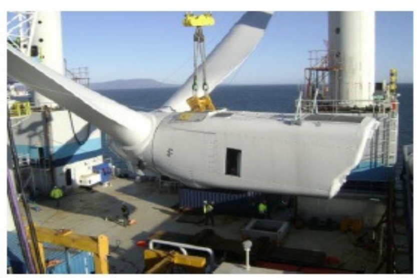
- China has the manufacturing capability to develop vessels for the industry, and has built a number of installation vessels for European customers
- Chinese companies have begun to develop vessels tailored to China’s offshore market, leveraging experience from the oil and gas and shipping industries
- assumption of 80 foundations/year (KPMG for Europe) and 5 GW annual capacity growth/year by 2020: 12-13 installation vessels for China
- six vessels available in China, and six more in production
- no consideration of repair & maintenance and additional downtime due to Chinese weather conditions
- 2020-2030: acceleration of global OWP market




Special vessels to install wind turbines


A wind turbine is installed in several steps


Once the tower is fully installed, the crane will pick up the nacelle and the blades


Bunny ear method: Installation of the preassembled nacelle with two blades


Rotor star method: Installation of a pre-assembled hub with three blades


Installation complete

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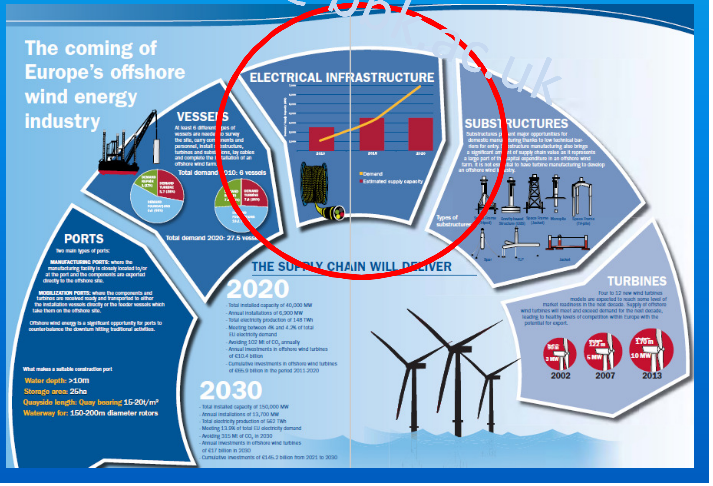
Cable layers

- two types: larger vessels for connecting OWP with terrestrial grid
- smaller vessels with high manoeuvrability ability for connecting individual turbines of OWP
- overall ageing fleet, most orders for larger vessels, shortage expected for smaller vessels
- shortage of up to 15 cable layers for EU alone
- timely grid connection might be Achilles heel
- example Germany: up to two year delay connecting OWP, reduction of national 2020 targets from 10 GW to 6.5 GW.



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Cable key project risks and high potential for O&M operations

- cable damage ~90% of the total number of insurance claims and ~70% of the total value of insurance claims in the industry cable related
- most failures due to human activity (e.g. fishing lines, anchors)
- burial of the cables best protection.

From: EWEA, 2011

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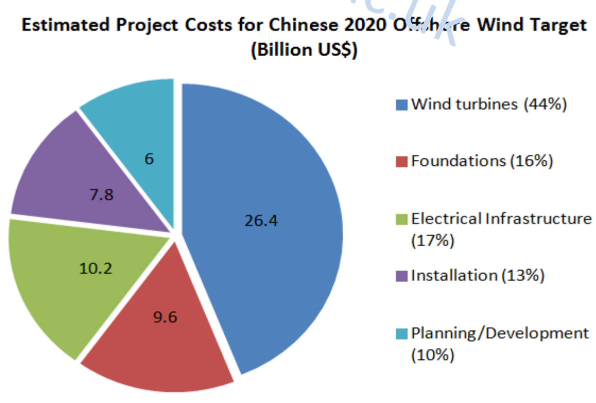
Cable Layers and the Chinese market

- potentially a major bottleneck with regard to cable installation vessels
- so far offshore wind industry adapted vessels used in the oil and gas and telecommunications industries
- only two specialised vessels available in the Chinese market in 2014 and two companies with plans to build offshore cable installation vessels (S.B. Submarine Systems and Zhejiang Seahead Ship Design)
- with offshore sites moving to deeper waters further from shore, size of cables increasing, there will be increasing need for larger bespoke cable-laying vessels



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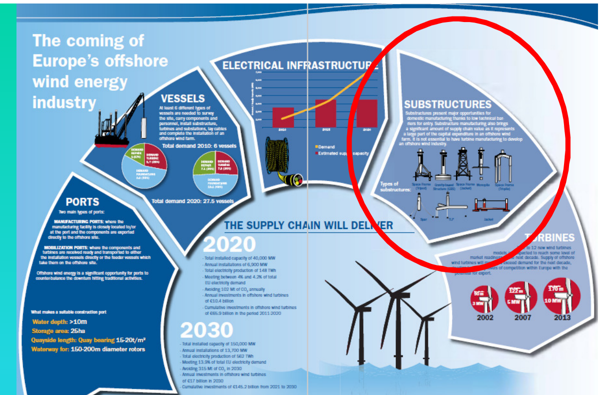
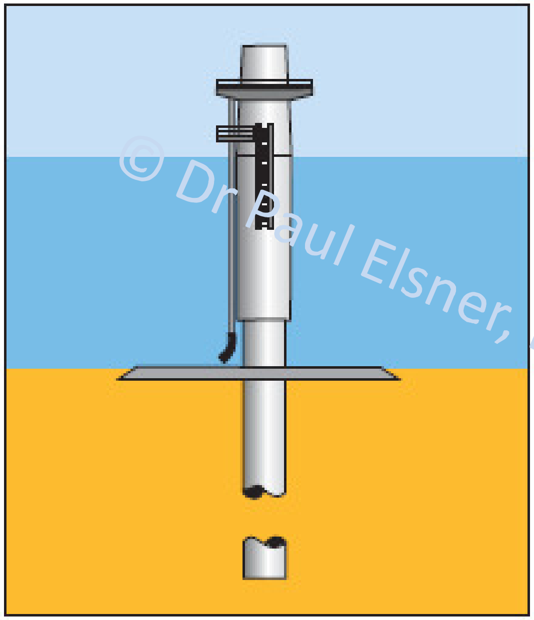
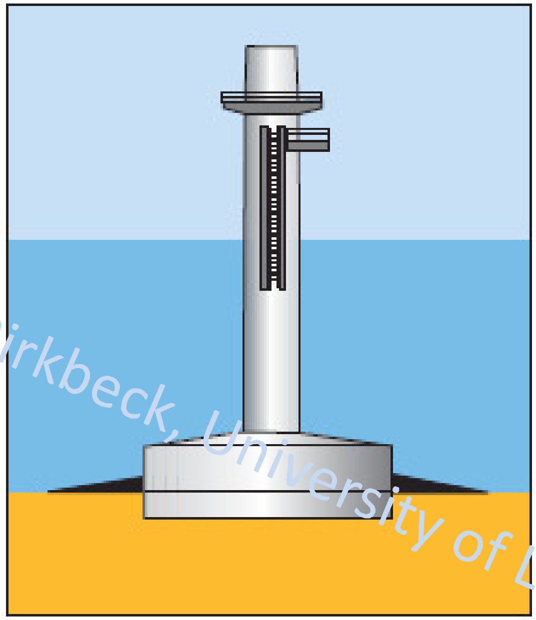
Substructures





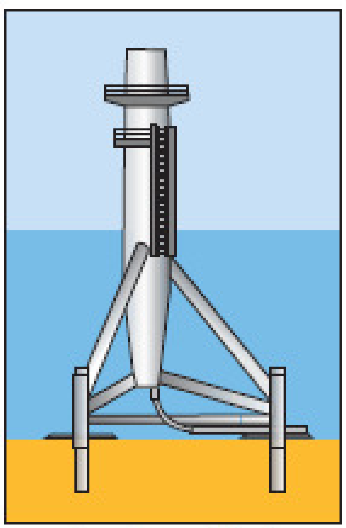
Monopile

from: EWEA, 2011

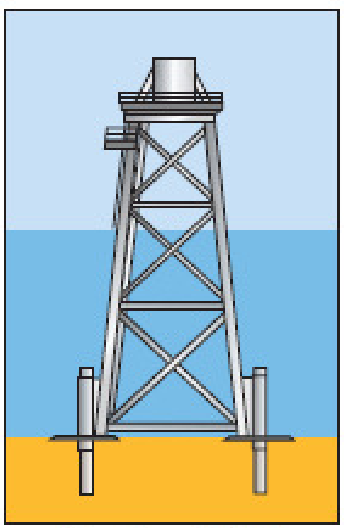


Gravity-based Structure (GBS)

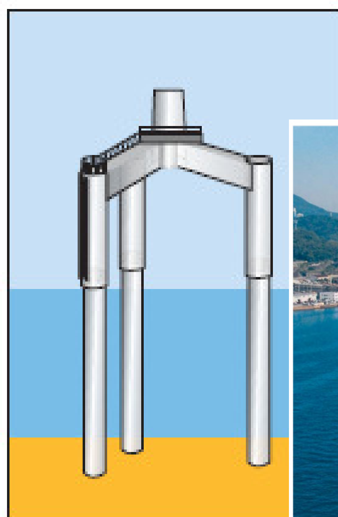
- China: demand for 5000 foundations by 2020 (assuming 6 MW turbines)



Space Frame (Tripod)



Space Frame (Jacket)



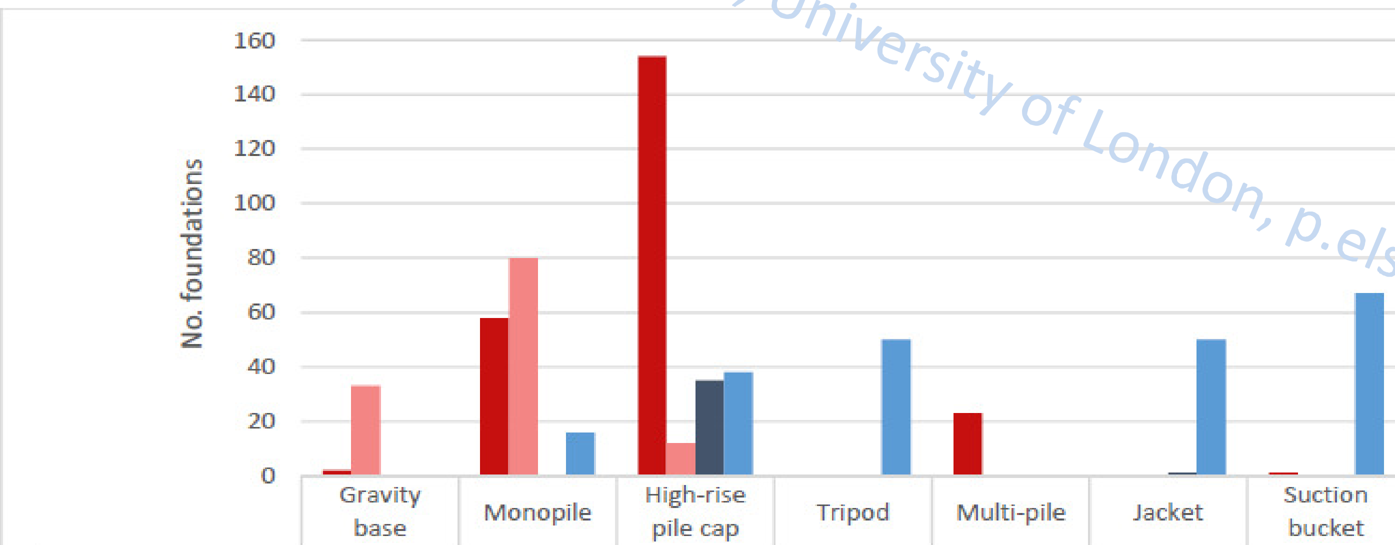
Space Frame (Tri-pile)

Fukushima Forward floating platform sets sail from Nagasaki port © Fukushima F

Foundation Challenges for China

- sea bed off China's east coast usually soft and silty
- different for soil conditions in Europe, making it difficult to leverage EU experiences
- Selecting appropriate foundations will therefore be crucial,
- scope for local R&D to develop bespoke solutions for China.

Fig.6.2.4. Foundation types (installed and pipeline) in intertidal and offshore zones in China.*



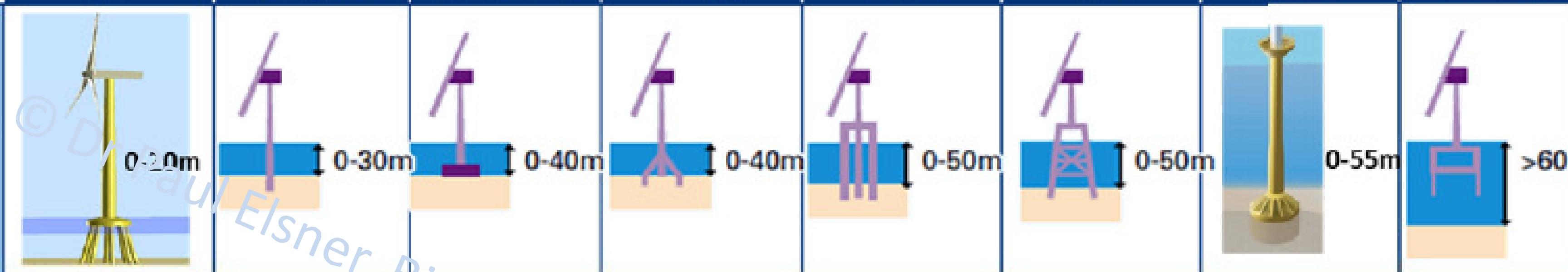
	Gravity base	Monopile	High-rise pile cap	Tripod	Multi-pile	Jacket	Suction bucket
Intertidal (installed)	2	58	154	0	23	0	1
Intertidal (pipeline)	33	80	12	0	0	0	0
Offshore (installed)	0	0	35	0	0	1	0
Offshore (pipeline)	0	16	38	50	0	50	67

*N.B. The majority of planned sites (over 1,200 turbines) have yet to select a foundation type.

Source: www.4coffshore.com; Carbon Trust analysis.

From: Rodriguez et al., 2015

Fig.6.2.3. Summary of the different foundations available for offshore wind turbines.



	High-rise pile cap	Monopile	Concrete gravity base	Tripod	Tri-pile	Jacket	Suction Bucket	Floating
Design	0-10m	0-30m	0-40m	0-40m	0-50m	0-50m	0-55m	>60m
E.g.	Donghai Bridge (CH)	Longyuan Rudong intertidal (CH)	Guodian United Power 6MW prototype (CH)	Longyuan Rudong intertidal (CH)	Bard Off-shore 1 (DE)	CNOOC Bohai Demo Turbine (CH)	DaoDa DDHI Test Project (CH)	Hywind (N)
Pros	Cap protects against maritime collisions	Simple design	Cheap No drilling	More stable than monopile	More stable than monopile	Stability Light	Less steel No drilling	Allows deep water use
Cons	Limited water depth Complex manufacturing	Diameter increases significantly with depth Drilling	Seabed preparation required	Cost More complex installation	Cost More complex installation	Cost More complex installation	Only applicable to soft seabeds	Cost
Comments	Unique to China Uncertainties on cost	Most widespread foundation type Limitations in water depth	Currently only used in shallow water	High production costs due to complex structure and weight	High production costs due to complex structure and weight	Commercially attractive >35m due to their flexibility and low weight (40-50% less steel than monopiles)	Yet to be deployed at scale	Currently at R&D stage, but could become relevant in areas with steep shores

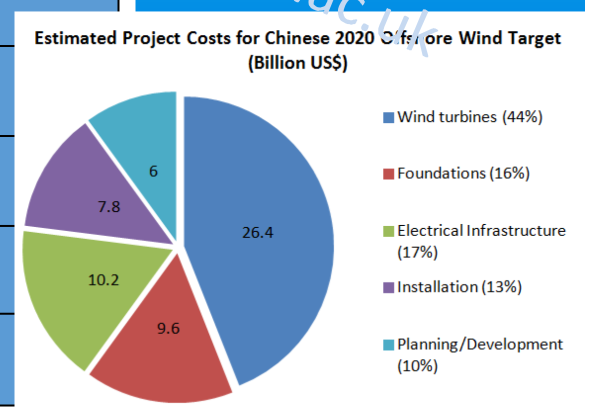
Source: Carbon Trust (2013).

Chinese key players involved in foundation sector

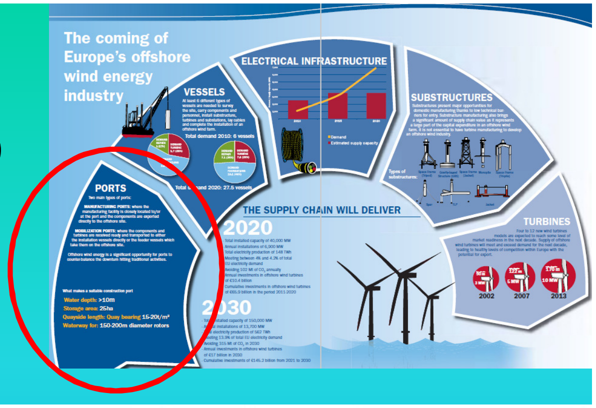
- opportunity to leverage its experience of designing and installing offshore oil and gas structures to service the offshore wind industry
- for production, little requirement for specialised wind energy technical knowledge
- opportunities for new market entrants

Company	Design	Fabrication	Installation
Shanghai Investigation, Design & Research Institute (SIDRI)			
Hydrochina Huadong			
Guangdong Electric Power Design Institute (GEDI)			
Jiangsu Longyuan Zhenhua Marine Co.			
China Offshore Oil Engineering Corporation (COOEC)			
Nantong Ocean Water Conservancy Engineering Co. (NOWCE)			
CCCC Third Harbour Engineering			
Jiangsu DaoDa Heavy Marine Industry (DDHI)			

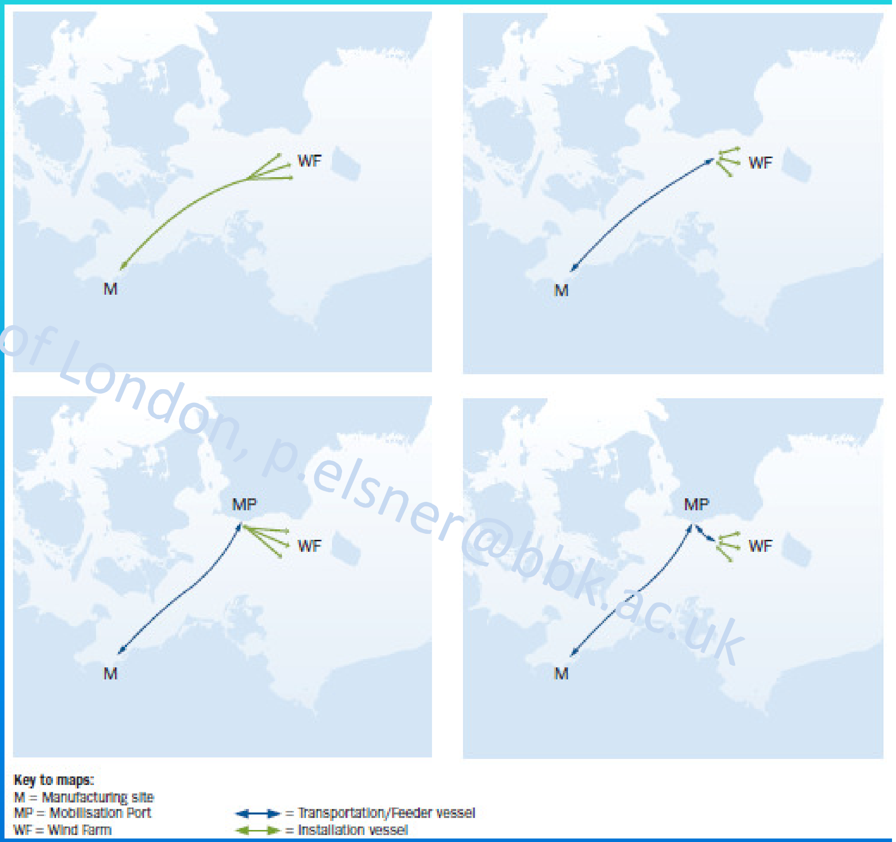
Source: Carbon Trust



Port requirements for OWP



- quayside length over 300 m, but no longer than 1 km
- quay should be able to bear weights of approximately 15 - 20 tonnes / m2
- allow jacking up right next to the quayside in order to use both the boat's own crane and the crane on the harbour
- crane or a gantry crane of 750 to 1,000 tonnes
- no access restrictions because of tide, locks or water depths (>10m)
- area of storage >25 ha for installation harbours, >50 ha if also manufacturing capacities



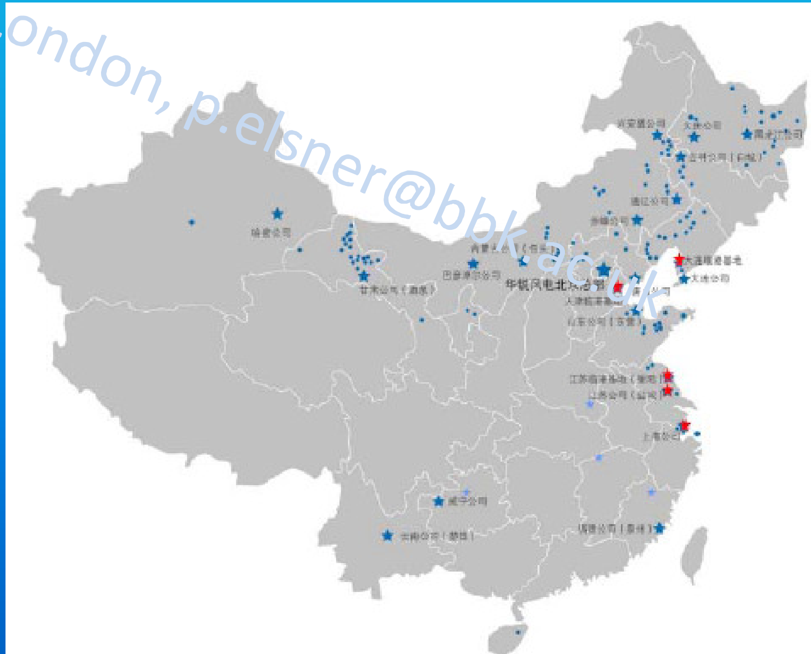
Approaches to turbine installation

From: EWEA, 2011

China port infrastructure challenge

- China currently no specialized ports for offshore wind development, turbine transportation and installation
- thus far been conducted from re-configuring existing ports and coordinating activities with other port functions
- increasing need for bespoke port facilities
- several Chinese wind power enterprises now constructing/planning large ports to expand their operations
- Jiangsu identified as a prime location

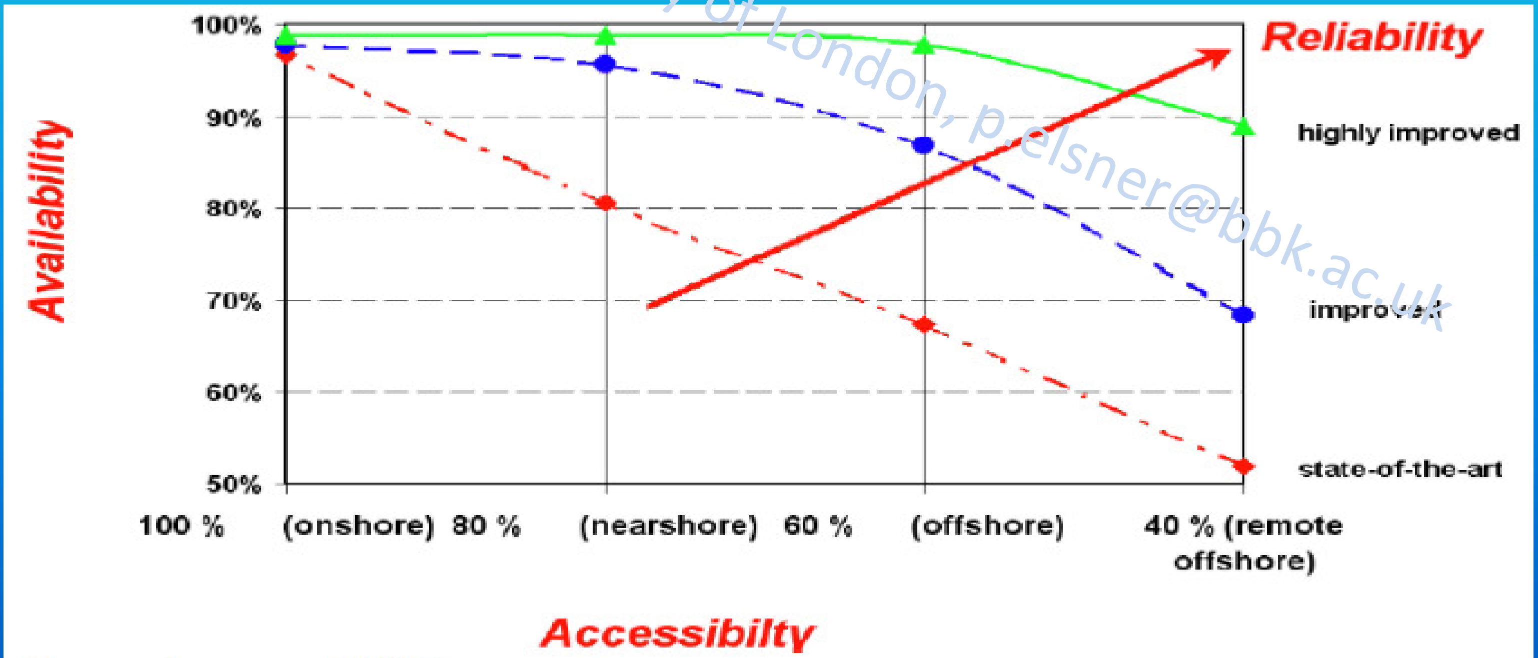
  e.g. Sheyang Port, Yancheng (Sinovel) and Dafeng (Goldwind)



*Blue stars = Sinovel branches; blue dots = Sinovel wind farms.

O&M/Service Vessels challenges for China

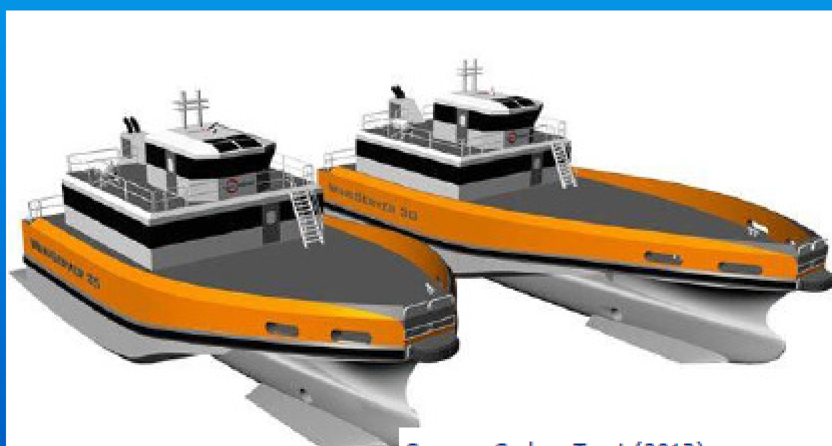
- Operations & Maintenance (O&M) inspecting, maintaining, and repairing the wind turbines.
- up to 25% of long-term project costs.
- China so far little experience of undertaking repairs offshore that are more complex than onshore turbines
- need to up-skill staff to be able to conduct repairs offshore
- ability needed to deal with reduced level of accessibility offshore



Source: Longyuan (2013)

Crew Transfer Vessels

- lack of expertise around transfer vessels
- currently use of traditional vessels to conduct maintenance.
- however, these vessels struggle to access turbines in difficult weather conditions and do not have bespoke transfer systems, which increases difficulty as well as health and safety risks.
- Particular problem when offshore wind farms are installed further from shore
- one bespoke O&M vessel will be required per 30 turbines installed in China (DNV-GL)
- equivalent to 200 vessels by 2020 for Chinese offshore wind markets.



Source: Carbon Trust (2013)

Fjellstrand "WindServer":

- Innovative hull design allows very fuel-efficient travel within the wind farm
- Unlike other fuel-efficient vessels, it is very stable when stationary which is ideal for transferring engineers to turbines
- Slender waterlines and unique bow ensures minimised motion at high speeds as well as during low speed manoeuvring in the wind farm
- Generous deck space made possible by the hull's ample load capacity can accommodate practically any transfer system

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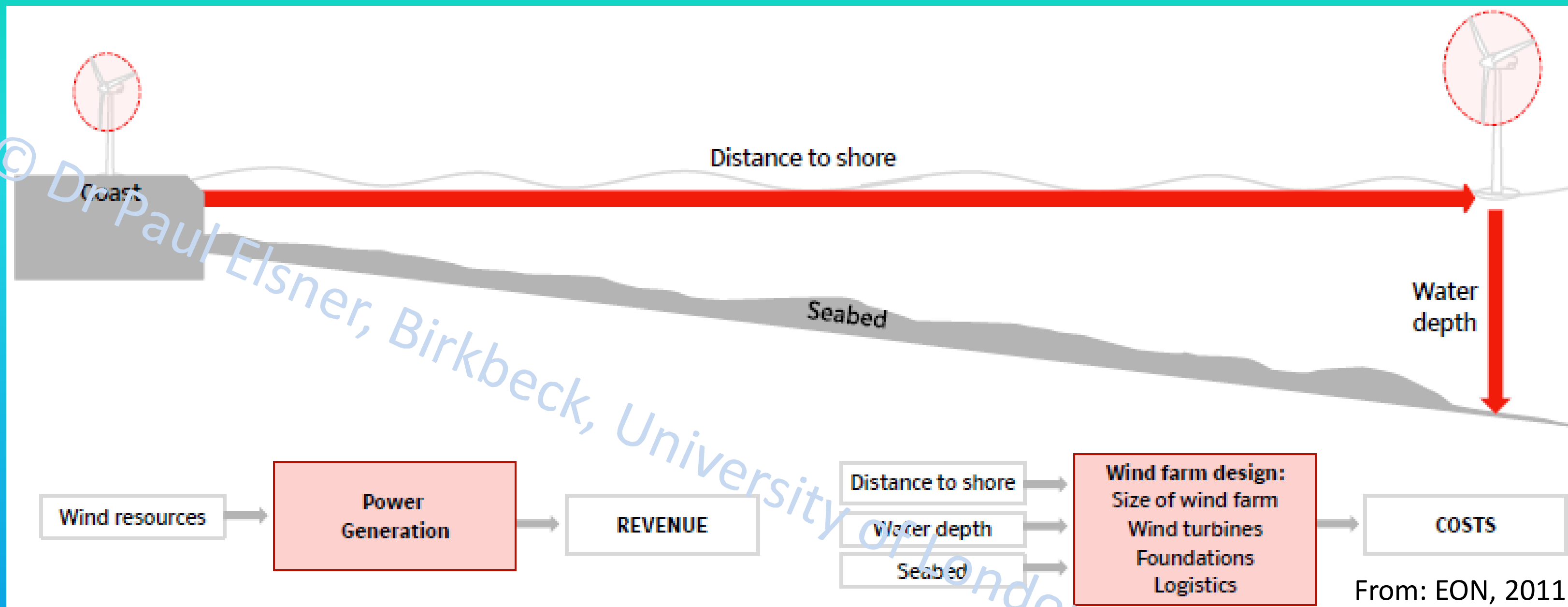
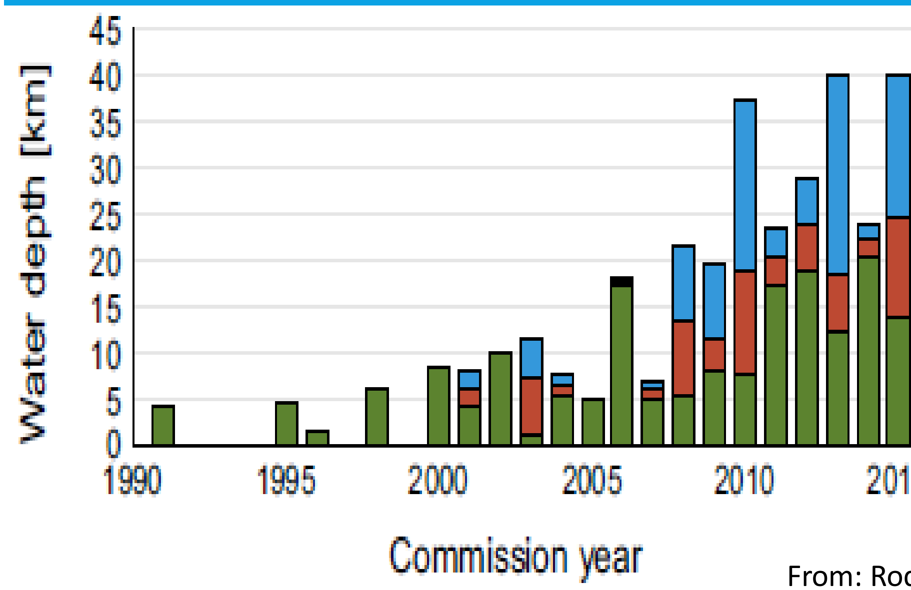
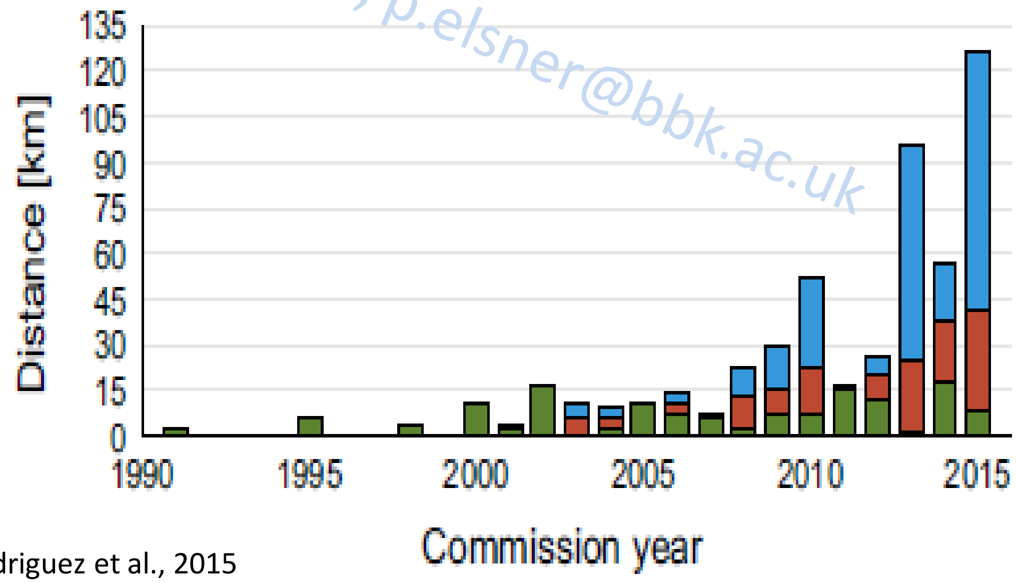
Trends for OWP and implications for the maritime industry



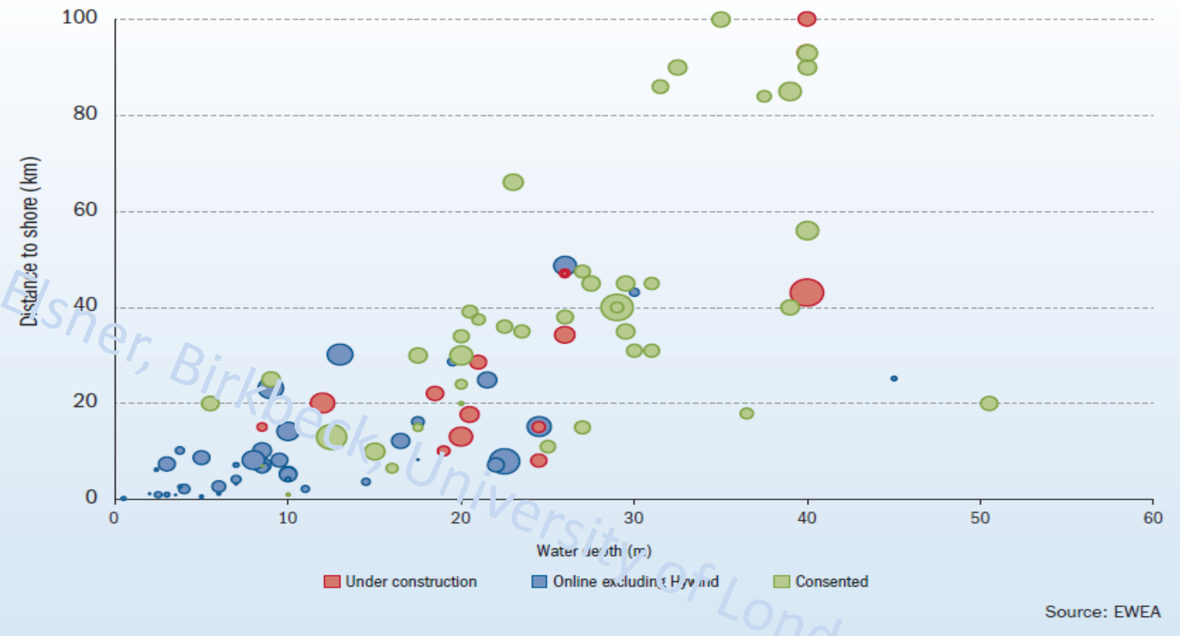
From: EON, 2011

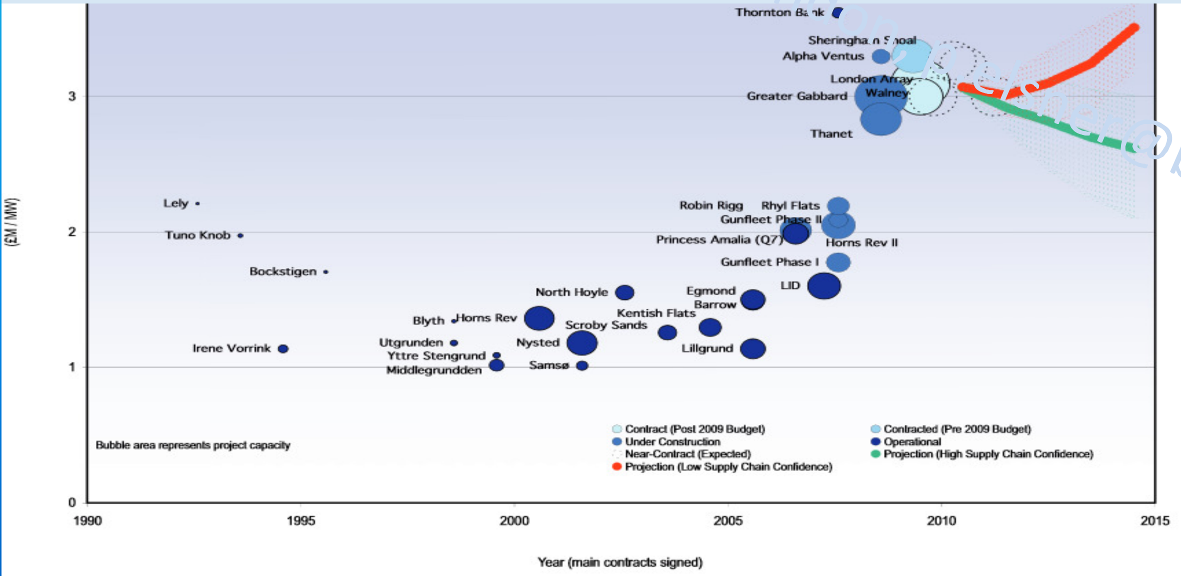




From: Rodriguez et al., 2015

Deeper, farer away – and higher costs





Historical, current and projected future capital costs for offshore wind projects

Grid connection infrastructure

- Need to design bespoke grid solution, e.g. (AC/DC), substations

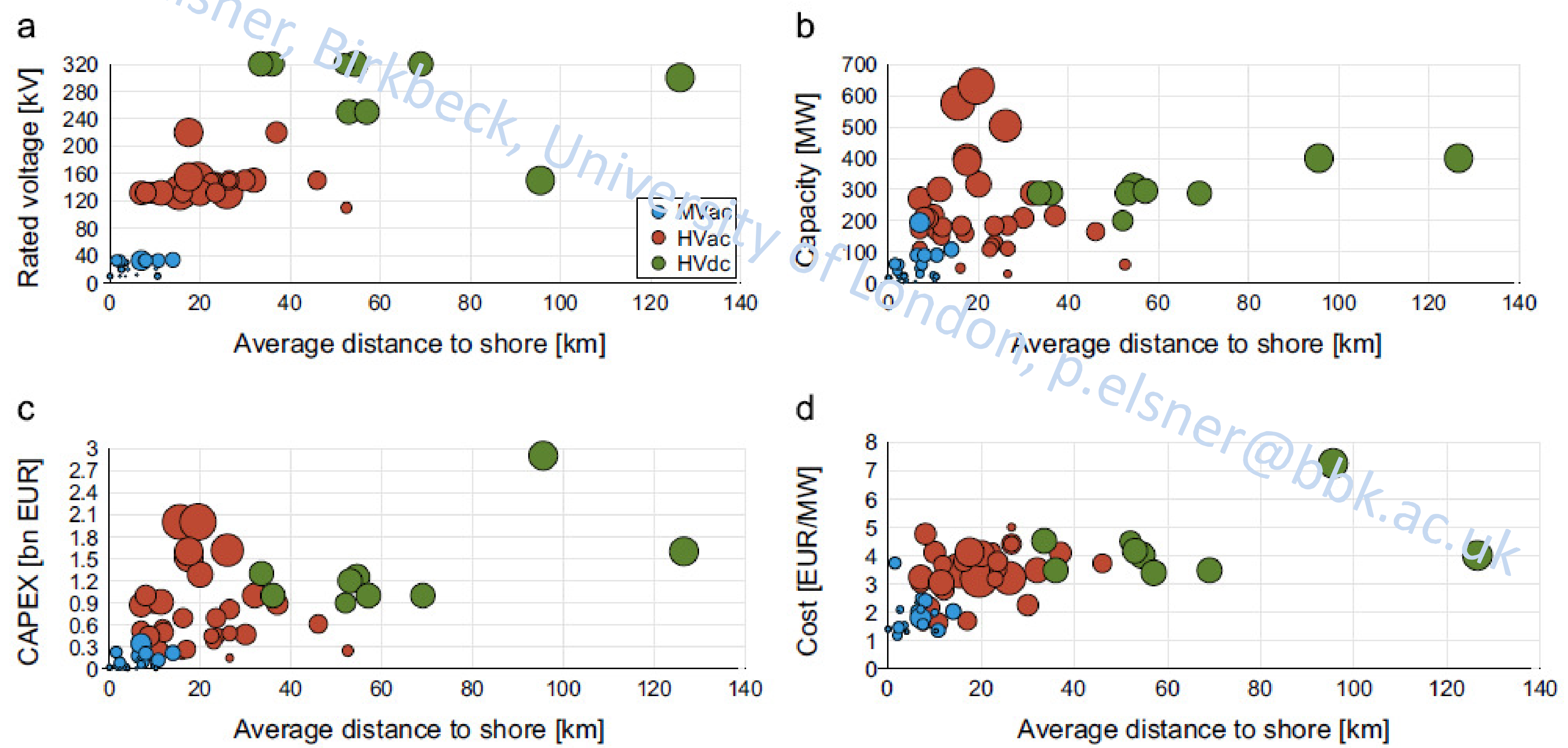
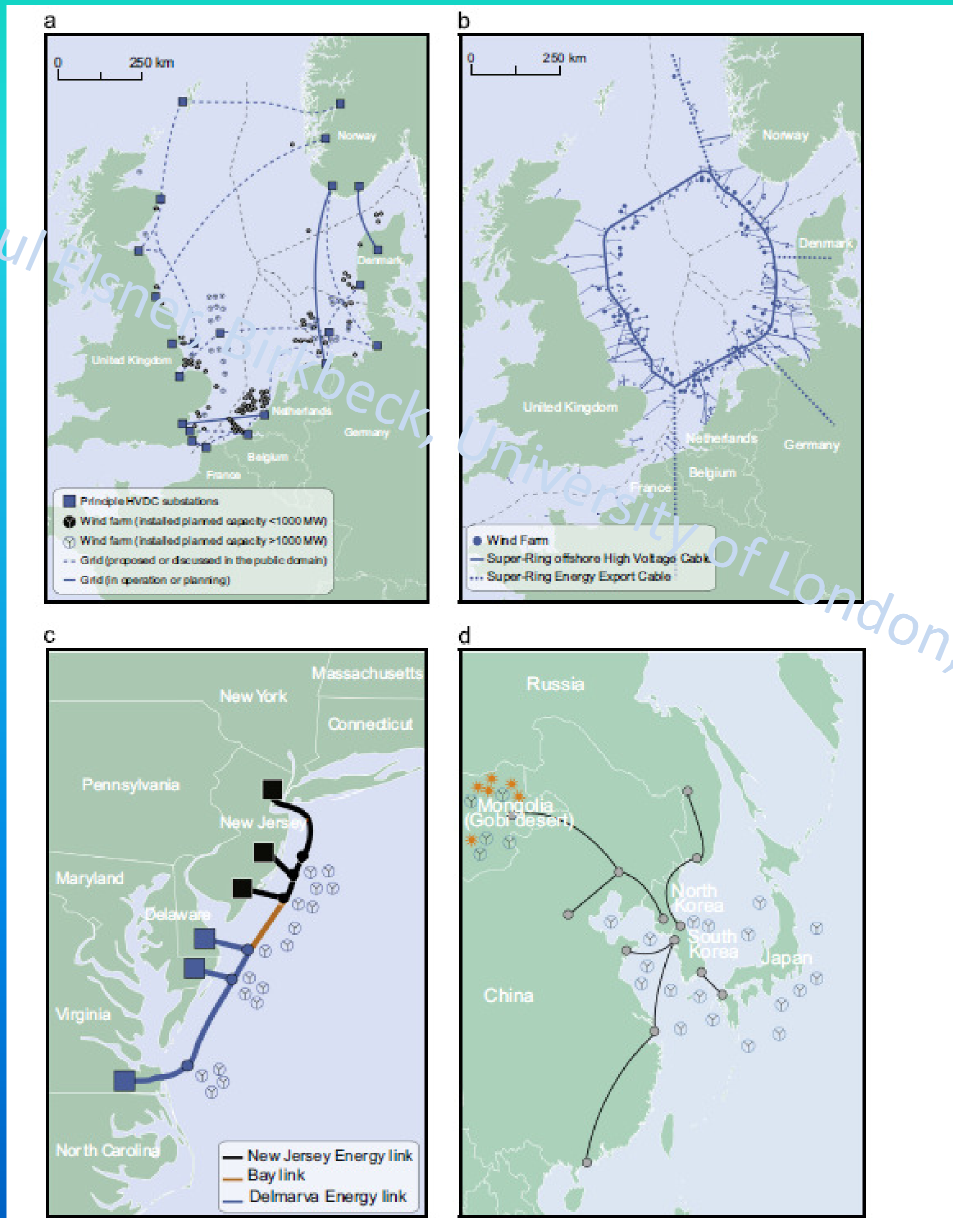


Fig. 9. Influence of the distance to shore on project's cost, installed capacity, transmission voltage level and technology for commissioned and under construction European OWPs composed of five or more turbines [15–17,38,21]. Bubble area represents the installed capacity of the OWPs.

From: Rodriguez et al., 2015

Planning the future supergrids



Proposals for future MTdc networks. (a) Greenpeace's proposal [151]. (b) OMA's vision [152]. (c) Atlantic Wind Connection [153]. (d) Asian Super Grid [157].

From: Rodriguez et al., 2015

Planning constraints and factors for OWP

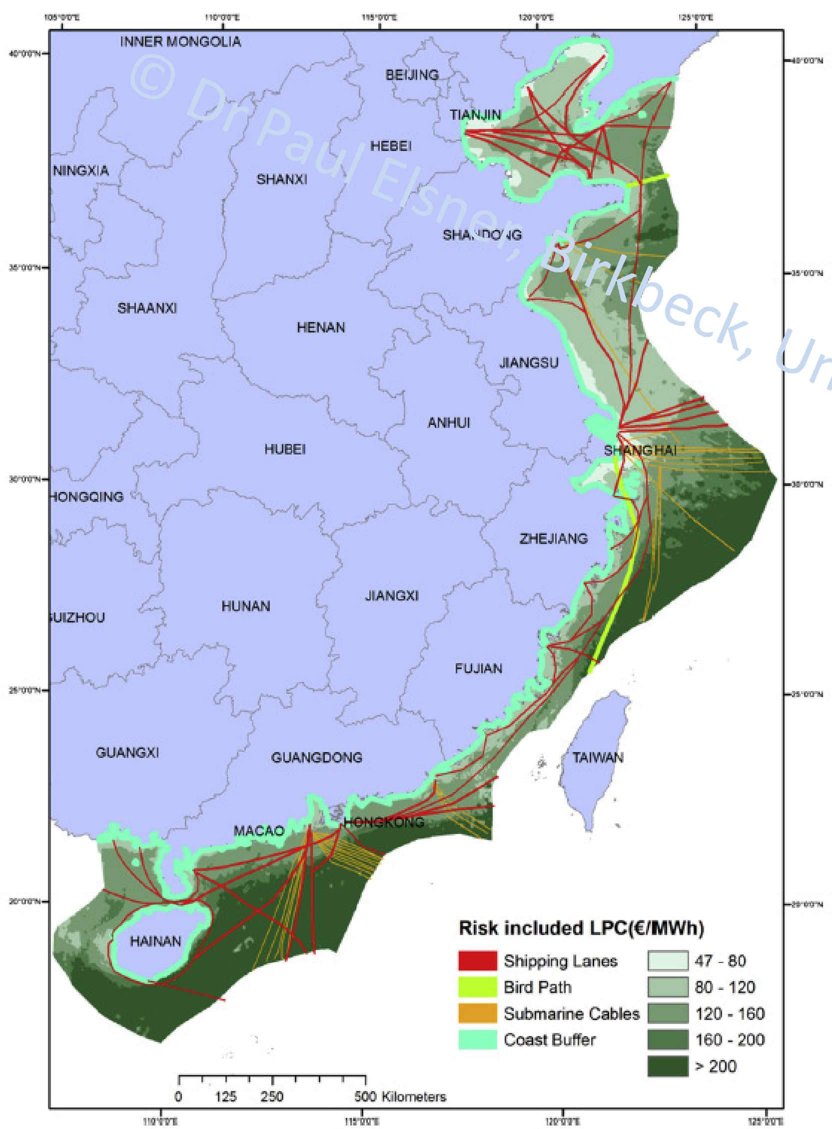
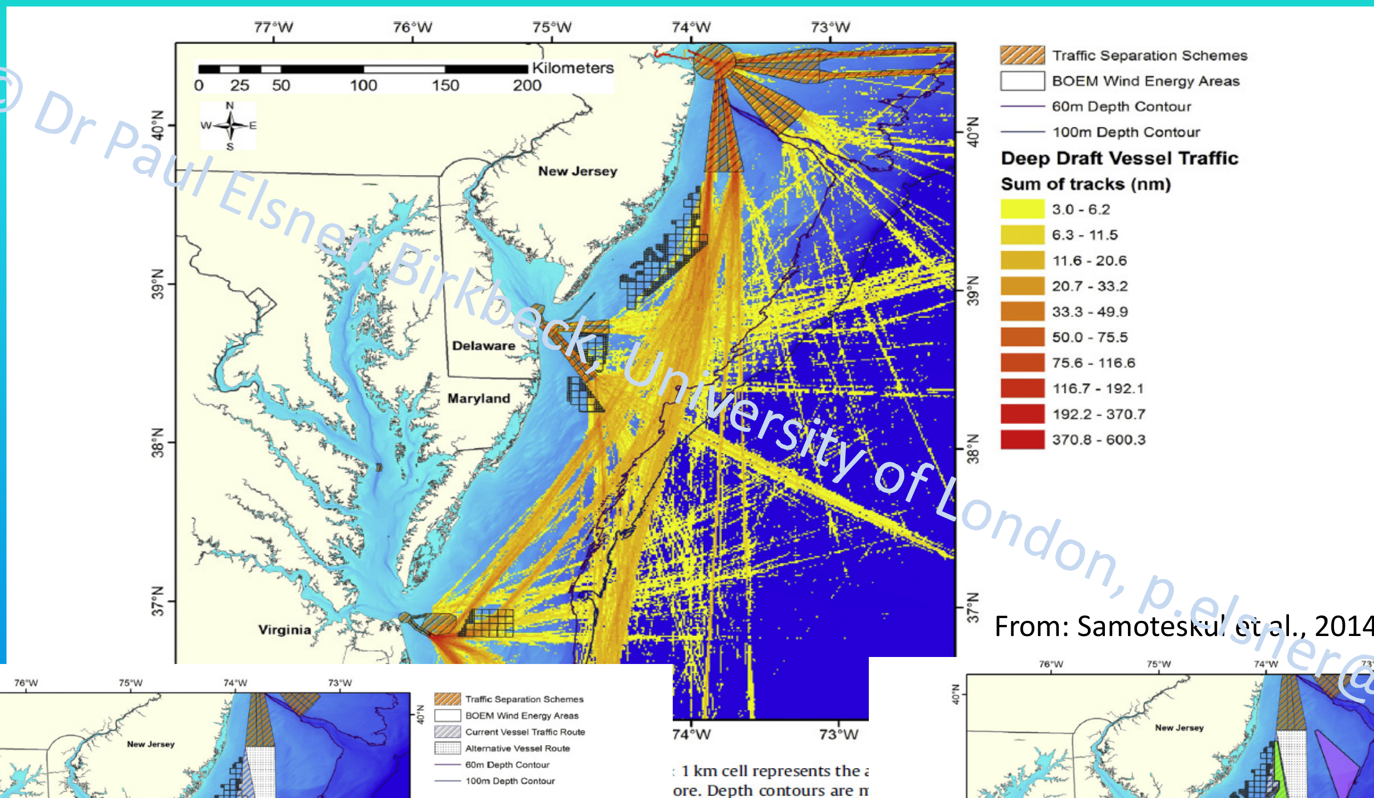


Fig. 6. Spatial distribution of LPC under tropical cyclone risk and spatial constraints.

- military operation or exercise zones
- piloting zones
- environmental protected areas
- shipping lanes and harbor entrances
- oil & gas lease or concession areas
- minimum distance to the high voltage grid
- distance to nearest port with sufficient capacity
- environmental impact
- seabed characteristics
- vessel traffic routes, seperation zones
- fishing areas
- extraction, dredging and dumping sites
- water depth
- pipelines (oil & gas) and cables(power & telecom) rights of way
- shipwrecks, UneXploded Ordnance(UXO)
- no anchoring areas

Offshore Wind potential conflict of uses – Example shipping



From: Samoteskul et al., 2014

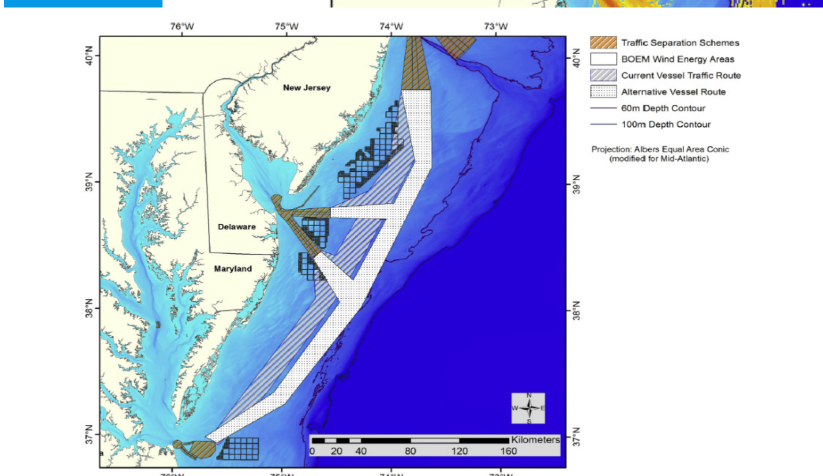


Fig. 2. The affected vessel route, used by ships transiting between the US Mid-Atlantic ports, is located nearshore. We are proposing to move this route farther from the coast.

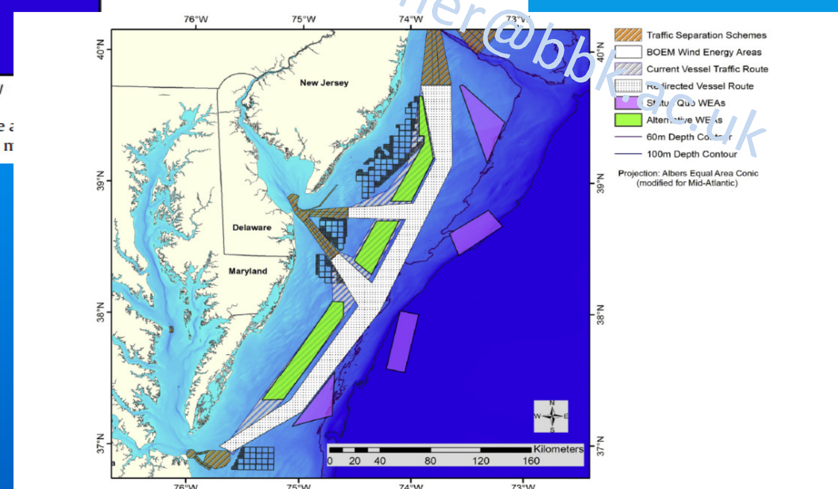


Fig. 3. The current vessel route and the proposed alternative route. The hypothetical Status Quo WEAs are located far offshore and Alternative WEAs are nearshore within the boundaries of the proposed alternative vessel route.

Competition for marine space example Belgian EEZ

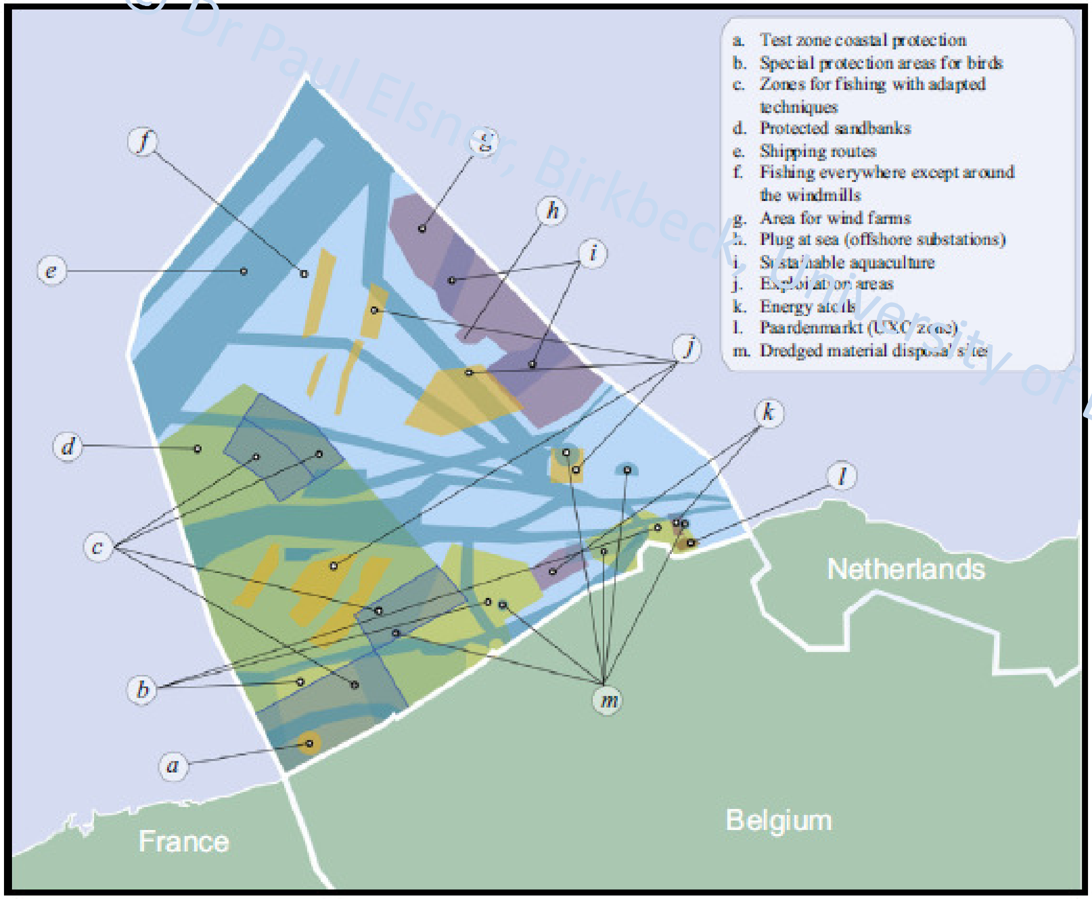
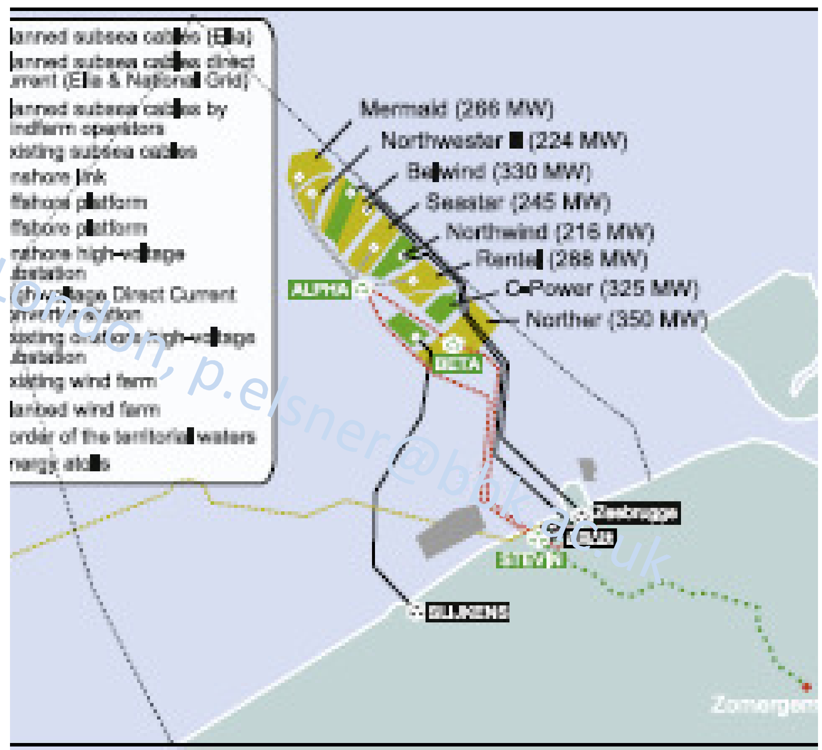
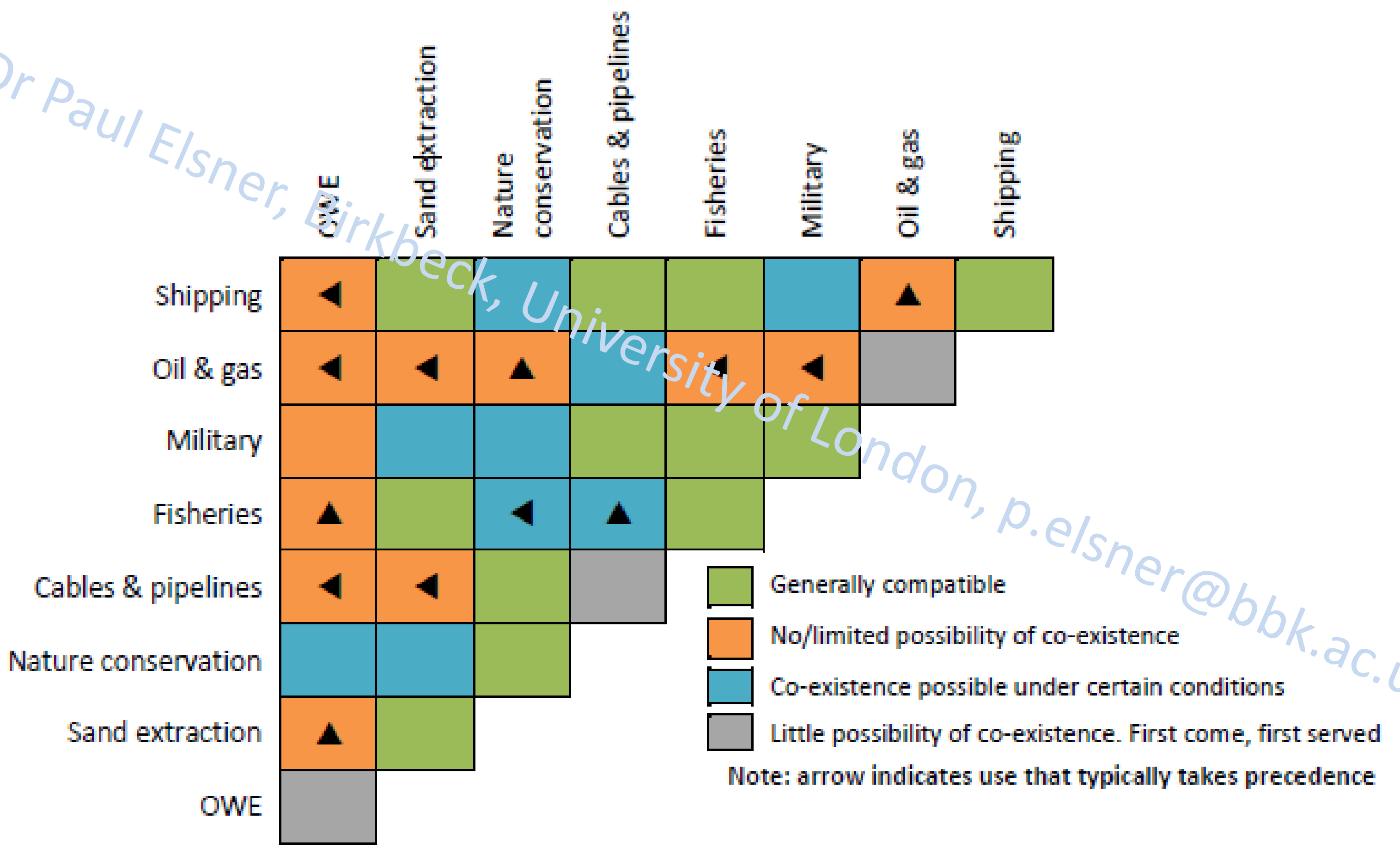


Fig. 2. Reserved areas of the Belgian EEZ [14].



From: Rodriguez et al., 2015

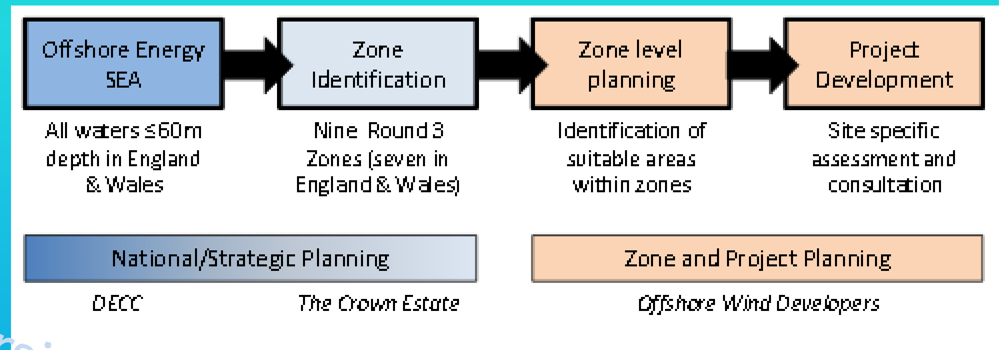
Potential stakeholder conflict



From: Veum et al., 2012

Need for integrated spatial planning Example UK

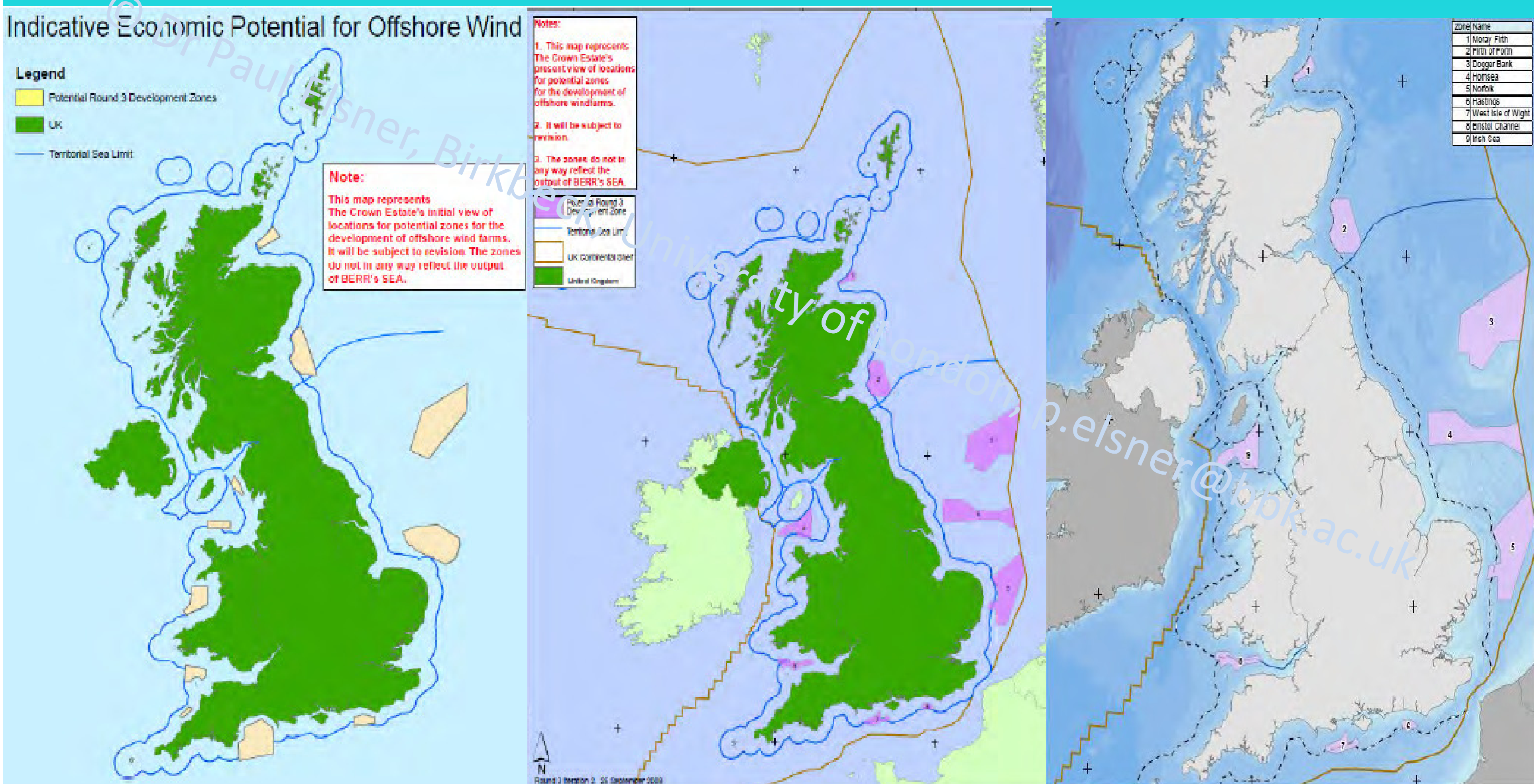
Round 3 Offshore Wind Site Selection at National and Project Levels



Round 3 zone concept

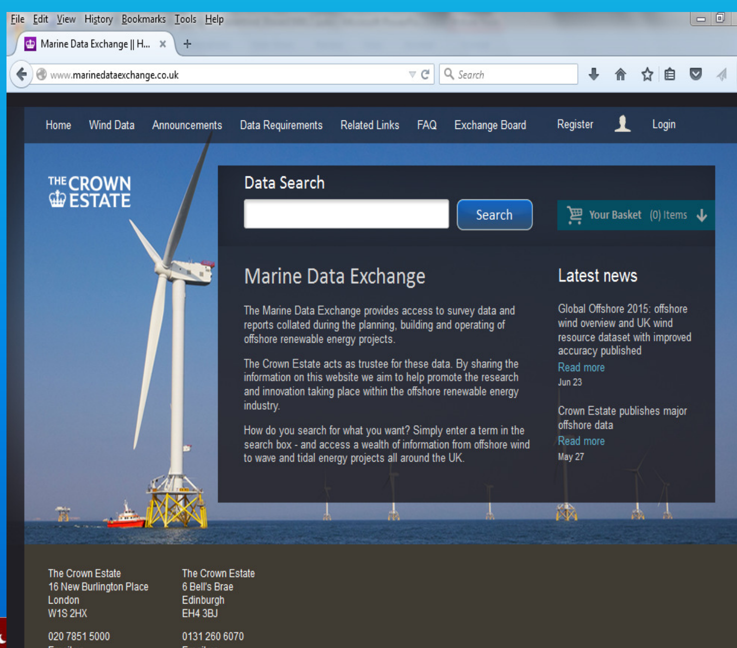
- previous piecemeal ‘project –by-project’ approach was unlikely to deliver the required capacity of offshore wind in the UK quickly enough
- nine development zones around the UK
- zone approach means that exclusive rights for the development of offshore wind over much larger areas of seabed were offered to developers
- allows individual developers to explore the potential for offshore wind across their zone, in a more planned and co-ordinated way
- space for multiple offshore wind projects in individual zones
- Nine development zones around the UK

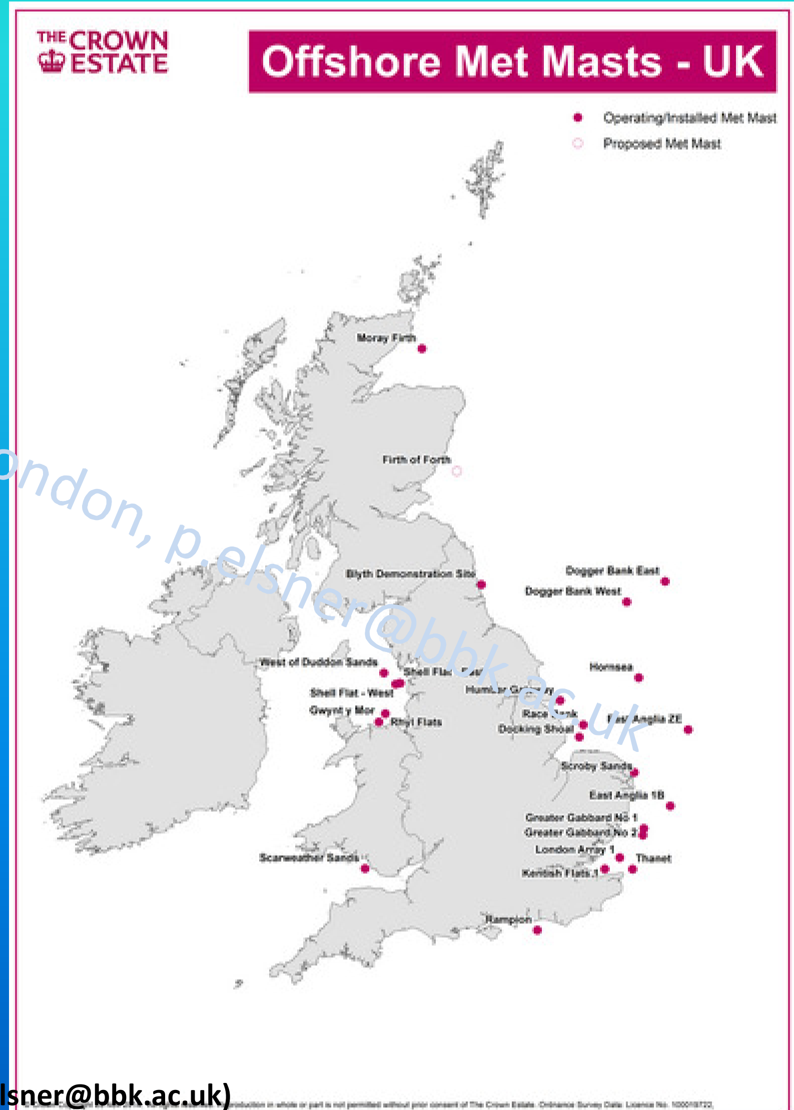
Optimised Spatial Planning using Marine Resource System (MaRS) GIS tool



Marine Data Exchange

- Operated by The Crown Estate
- free access to geotechnical, geophysical and environmental survey data gathered during the planning, building and operation of offshore renewable energy projects.





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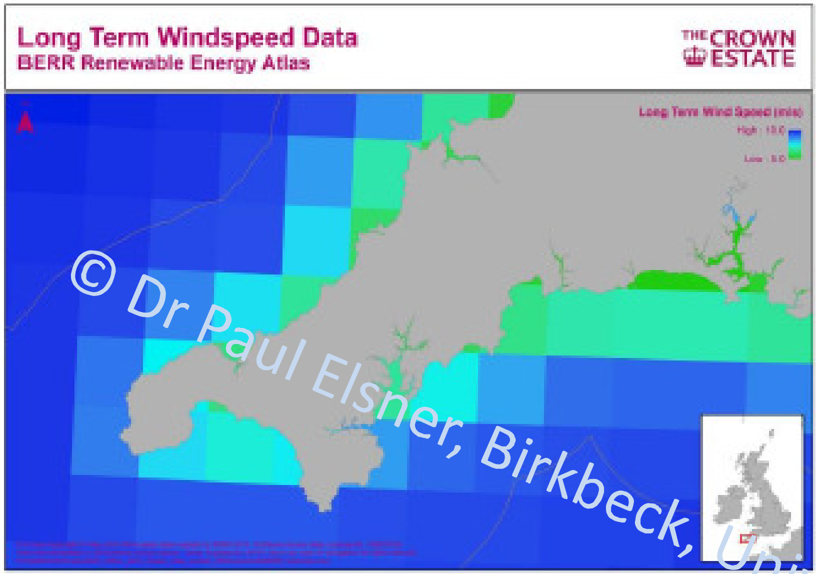


Figure 1 The Atlas of UK Marine Energy Resources 2008 - Cornwall

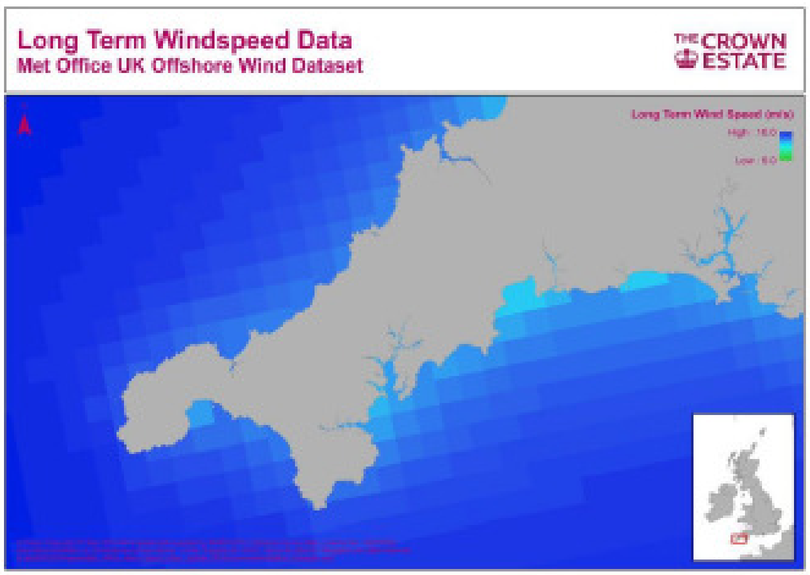
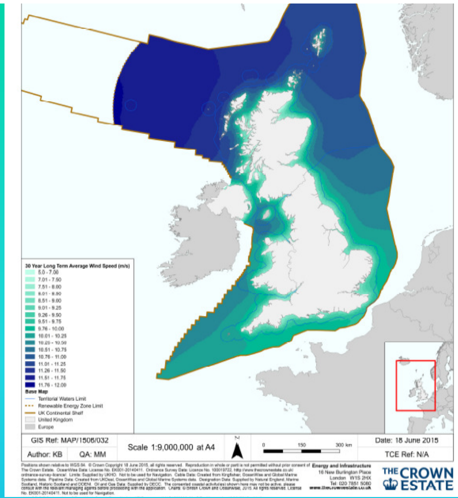


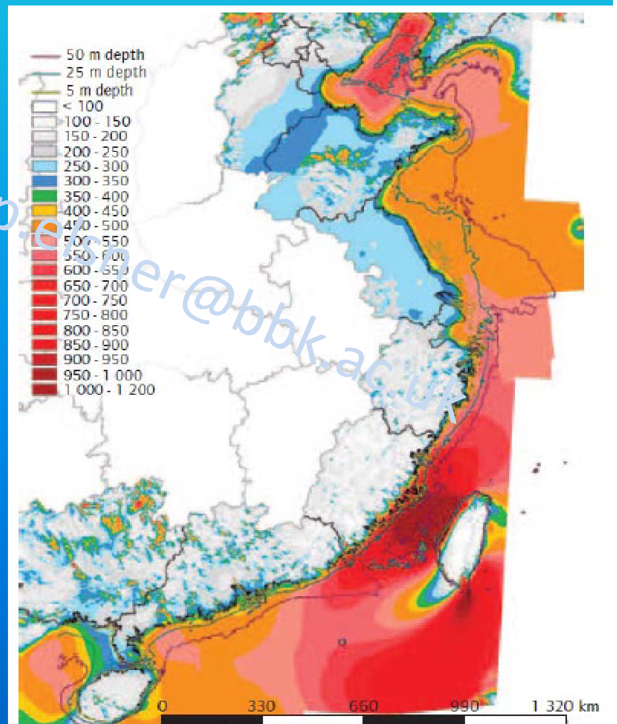
Figure 2 The UK Offshore Wind Dataset 2015 - Cornwall



- **2015 dataset – key features**
- hindcast period is 30 years (7 years in 2008 data)
- hub height modelled at 110m
- increased spatial resolution to 4.4 km resolution
- additional modelling using a 1.5km model around the coastline (12 km in 2008)

Need for detailed offshore wind resource information in China

- to date, only macro-level wind resource assessments
- lack of accurate wind resource data at site scale
- wind speed critical in determining the commercial viability of wind power projects.
- ccurate wind resource measurement to ascertain the power output of a site is therefore crucial before making expensive offshore investments.



Distribution of annual average wind power densities in 5-50m depth sea areas

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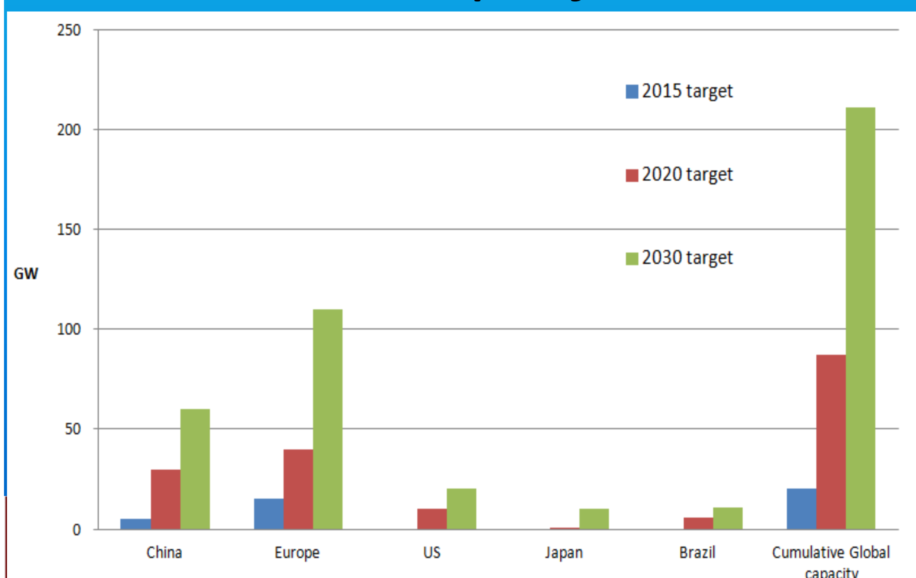
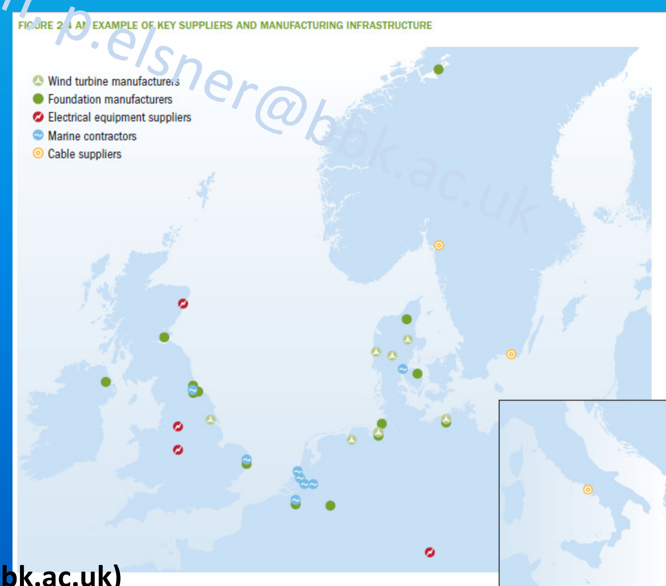
Offshore wind as emerging global market

- growth in 2020-2030: 120 GW
- assuming optimistic costs expectations of 1.5 million US$/MW = 180 billion US$
- 40% share for maritime operations: 72 billion US$
- advantages for existing players in the market with reference projects





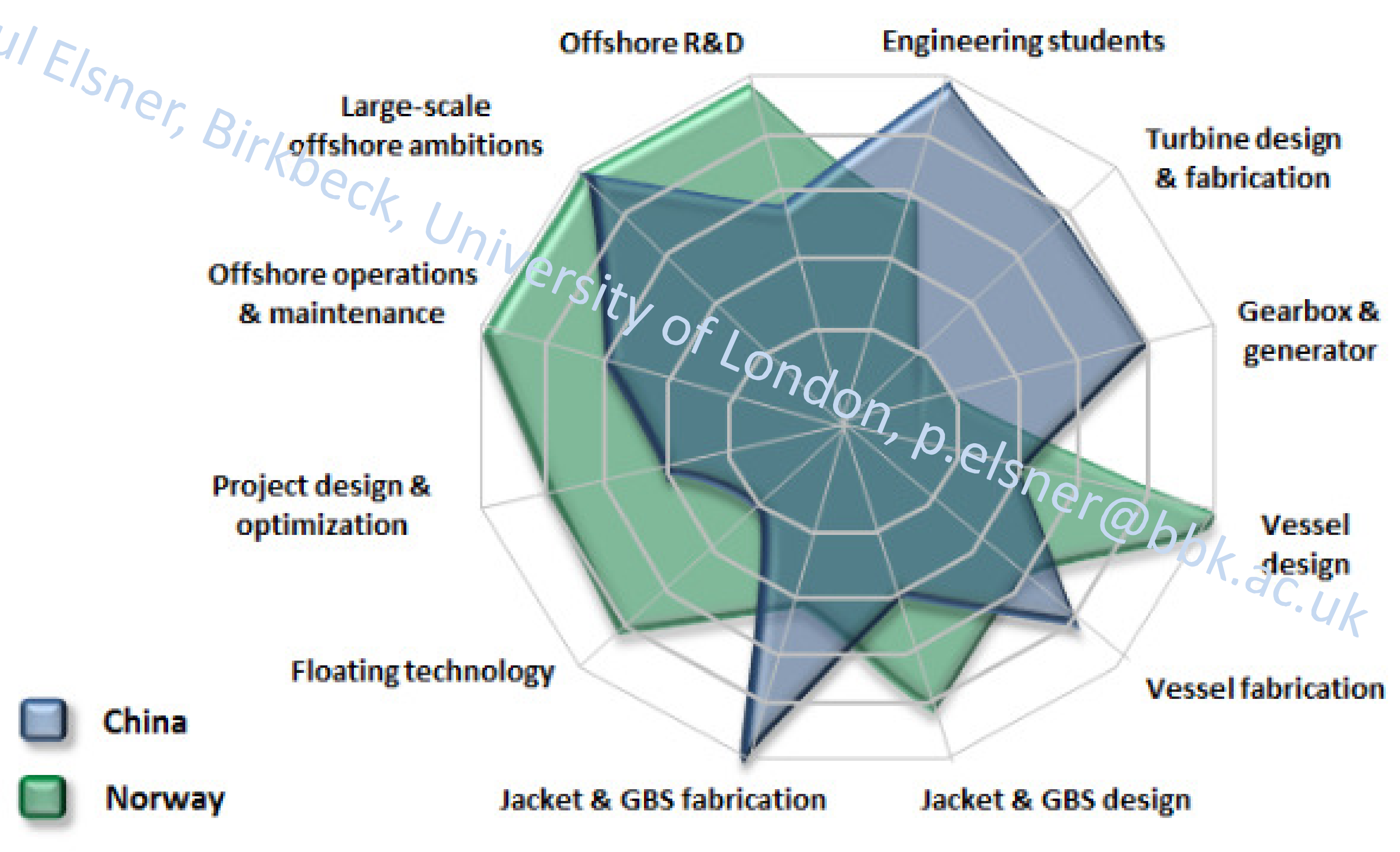
Challenges for China's Offshore Wind Sector: 50% of them are maritime

Category	Challenge	Priority
Policy	Lack of sustainable incentive mechanism (FIT)	High
	Poor government coordination around consenting	Med
Developer	Poor wind resource data	High
	Limited information on wake effects	Med
	Excessive time for wind farm development	Med
	Limited project development experience	High
Infrastructure/ Connectivity	Offshore substations	Med
	Supply of 220kV cables	Med
	Cable installation vessels	High
Turbines	Gearbox reliability	High
	Generator efficiency	High/Med
	Blade length and weight	Med/Low
	Supply of control systems and power converters	Med/Low
	Resistance to typhoons	Med
	Corrosion and over-heating	High
Foundations	Low stability in soft seabed conditions of current designs for offshore	High
	Corrosion issues	Med/Low
	Fatigue issues	High
	Transition piece connection challenges	High/Med
	High cost	High/Med
	Ease of installation	High/Med
Installation	Inadequate expertise of piling hammers	Med
	Installation vessel availability	High/Med
	Installation rate	Med
	Incidence of cable damage	High/Med
	Lack of installation experience	High/Med
Operations & Maintenance (O&M)	Quality of condition monitoring systems	Med
	Limited availability of access vessels	High
	Limited availability and design of transfer systems	High/Med
	Lack of O&M experience	High/Med

Source: Carbon Trust

From: Caron Trust, 2014

Opportunities for the international maritime sector (incl. oil & gas): example Norway



Source: Innovation Norway

Offshore wind energy: China's second mover advantage

- opportunity to benefit from costly experiences of pioneering European countries.
- No need to re-inventing the wheel
- opportunity to identify potential European partner on project-to-project base
- large portfolio of European projects available (intertidal, deep water, planning approaches, grid solutions)
- China's own OWP will establish platform of reference projects to enter other global markets in next decade
- Offshore wind becoming significant new global market, resembling development of offshore oil & gas since 1970's

Thank you

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